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NASA THUNDERSTORM OVERFLIGHT PROGRAM – RESEARCH IN ATMOSPHERIC ELECTRICITY FROM AN INSTRUMENTATED U-2 AIRCRAFT PLATFORM

By Otha H. Vaughan, Jr.
Systems Dynamics Laboratory

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Space Administration
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16. ABSTRACT

This report presents an overview of the NASA Thunderstorm Overflight Program (TOP) being conducted by the Marshall Space Flight Center and university researchers in atmospheric electricity. Discussed in this report are the various instruments flown on the NASA U-2 aircraft, as well as the ground instrumentation used in 1982 to collect optical and electronic signatures from the lightning events. Samples of some of the photographic and electronic signatures are presented. Approximately 6400 electronic data samples of optical pulses were collected and are being analyzed by the NASA and university researchers. A number of research reports are being prepared for future publication. These reports will provide more detailed data analysis and results from the 1982 spring and summer program.

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ACKNOWLEDGMENTS

The successful accomplishment of any research program requires the efforts and cooperation of the many individuals and groups who contribute so much to the operational aspects of the aircraft and data collection instrumentation and analysis of the data during the program. Foremost among those to whom we are indebted over the past few years are Dr. James C. Dodge, NASA Headquarters, who provides the funding for the U-2 Aircraft operations and the instrumentation development and the U-2 pilots Jim Barnes, Bob Erickson, Ron Williams, Jerry Hoyte, and Iva Webster. Also, we appreciate the dedicated efforts of Dr. John Arvesen and James Cherbonneaux, NASA, Bob Ekstrand of Analytical Technologies Applications Corp., and Norm Lefleur, Bob Danielson, and the many other support personnel of the Lockheed U-2 support group at Ames Research Center.

In addition, I would like to acknowledge the efforts of the MSFC "OLDE" team members, Dr. P. H. Gillaspy, Mr. S. Goodman, Mr. L. Frost, and Dr. H. Christian, and to the atmospheric electricity research personnel from NOAA/SSL, Dr. David Rust, Mr. B. Taylor, and from the university researchers, Dr. B. Vonnegut and Dr. R. Orville of SUNYA and Dr. M. Brook, Dr. P. Krehiel, and Mr. C. Rhodes of NMIT who provided various types of data for inclusion in this report.

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NASA THUNDERSTORM OVERFLIGHT PROGRAM – RESEARCH IN ATMOSPHERIC ELECTRICITY FROM AN INSTRUMENTATED U-2 AIRCRAFT PLATFORM

I. INTRODUCTION

The Thunderstorm Overflight Program (TOP) is being conducted by NASA, NOAA, and several universities to evaluate the feasibility of making measurements of lightning from an instrumented platform above thunderstorms. A NASA U-2 high-altitude research aircraft (Fig. 1) has been used to conduct this type of research since the summer of 1979. The overall research objectives are (1) to develop design criteria for a proposed lightning mapper satellite system that may be used to monitor the evolution of severe storms and (2) to study lightning physics and correlate lightning activity with storm characteristics such as cloud heights, temperature, updraft velocity, etc. In addition, the research is useful in the analysis of data obtained from the Nighttime/Daytime Optical Survey of Lightning Experiment (NOSL) [1-4] flown during the recent flights of Space Shuttles STS-2, STS-4, and STS-6, and in providing design criteria for a future lightning mapper satellite [5]. Figure 2 describes the objectives of the Thunderstorm Overflight Program and names the scientific investigators. Previous research from this program (TOP) can be found in References 6, 7, and 8. Figure 3 shows the project management structure for the 1979 through 1982 lightning research program.

The feasibility of using a modified low-light level TV camera as a lightning detector and collecting spectral signatures of cloud-to-ground and intracloud flashes was evaluated during 1979 from both airborne and ground sites. Details of this research can be found in Reference 9. In early 1981, the research program was restructured to incorporate new instrumentation into the previous U-2 instrumentation package, and is now called Optical Lightning Detection Experiment (OLDE). The new instruments were a solid-state TV camera and an improved lightning-detection sensor system developed by the University of Arizona Optical Sciences Center (UAOSC) under NASA/MSFC contract. The U-2 operations and the lightning research program have been supported by the NASA Office of Space Sciences and Applications, Severe Storms and Local Weather Research Program Office.

This report is an overview of the NASA/MSFC U-2 Atmospheric Electricity Research Program as of August 1982. During the spring and summer of 1982, a number of TOP/U-2 research flights were conducted. The U-2 aircraft carried an instrumented pallet on which a number of the previous and new sensors were installed. The new instrumentation hardware on the pallet is part of the Optical Lightning Detection Experiment (OLDE). A preliminary analysis of some of the data collected during this time will be presented later in this report. A number of research papers are being prepared, which will give a more detailed analysis of the 1981 data. Reference 10 presents some of the preliminary data for the spring 1982 flights. The objectives of the experiment and the instruments and their characteristics are described. Figure 4 shows the present management plan for the OLDE, and Figure 5 shows some of the in-house hardware which is being used in the analysis of the data tapes produced by the U-2 sensors.

II. EXPERIMENT OBJECTIVES

The objectives of the OLDE are to provide design criteria data for the Lightning Mapper Satellite Program by establishing the following characteristics:

1) The reflectivity, intensity, and variability of the cloud top background.

2) The absolute intensity of lightning-generated optical emissions radiating from the cloud tops.

3) The temporal and spatial variability of lightning-generated emissions.

4) The spectral characteristics of lightning-generated emissions:

   a) Absolute intensities as a function of wavelength.

   b) Emission line widths and variability with particular emphasis at λ = 7774 Å and λ = 8683 Å.

III. INSTRUMENTATION

A. Spring 1982 Program

The instrumentation pallet for the U-2 spring 1982 flights consisted of seven sensors, a magnetic tape instrumentation recorder, a video tape recorder, a time code generator, and a power supply module (block diagram, Fig. 6A). The sensors were:

1) Wide Angle Optical Pulse Detector (WAD)

2) Electrical Field Change Meter (ΔE)

3) Optical Pulse Detector (OPD)

4) Optical Array Sensor (OAS)

5) 1/8 Meter Ebert Spectrometer (BBS)

6) CCD TV Camera

7) Photography Time Lapse Cameras (2 each).

The recorders were:

1) A 14-Channel Sangamo Sabre 80 Instrumentation Recorder

2) A Panasonic Video Recorder.

A power supply module provided +24 V, +12 V, and +6 V from the U-2 28 V aircraft power supply to operate the instruments on the aircraft pallet. Figures 6A, 6B, and 7 show the spring 1982 instrumentation pallet-mounted and hatch-mounted instruments.

B. Summer 1982 Program

The instrumentation pallet for the U-2 summer 1982 flights consisted of seven sensors, the same tape recorder, video recorder, time code generator, and power supply used for the spring program, plus an additional sensor, a high resolution spectrometer (HRS), and a CAMAC data processor. For the summer program, the data collected by the Optical Array Sensor and the two spectrometers were digitized, and the pulse-coded modulated (PCM) bit streams were recorded on three channels of the Sabre 80 recorder. Eleven data channels of the other sensors were recorded in FM wide band II. A block diagram of the summer package is shown in Figure 8A, while Figure 8B shows the sensor layout.

In the following paragraphs, each of the sensors are described:

1) Wide Angle Optical Pulse Detector (WAD). The WAD (Fig. 9) was used to measure the optical pulses generated by the lightning. The WAD has a field of view (FOV) of 120 deg. Placed in front of the detector was a wide pass near-infrared filter (Brook, et al., 1980) having 85 percent maximum transmission at = λ 6560 Å. The detector was a silicon solar cell (Radio Shack 276-120) and was capacitor coupled to the initial amplifier stage with a 3 sec time constant.

2) The Electric Field Change Meter (ΔE). This instrument (Fig. 10), which senses the changes in the electric field caused by the lightning (Brook, et al., 1980), consists of a circular flat plate with a geometric area of 75.43 cm^2 and associated electronics. This meter was mounted on the bottom hatch window of the U-2.

3) Optical Pulse Detector (OPD). This instrument (Fig. 11), developed by UAOSC, is a narrow-angle, a.c.-coupled photo-diode with interference filters selected prior to flight, and is mounted in front of the detector. It has a 2-microsecond time resolution and a FOV of 1 radian, and is included in the same instrumentation container with the Optical Array Sensor. Its purpose is to detect optical flashes and provide wave form information from the flashes.

4) Optical Array Sensor (OAS). The Optical Array Sensor (Fig. 11), a 50 x 50 element photo-diode array manufactured by Reticon with a FOV of 1 radian, observes the lightning flash through a narrow-band interference filter which is selectable prior to flight. Since the OPD and the OAS are used together, the interference filters are the same for each flight. This sensor, a scene-imaging system with a 150-meter resolution at cloud top, has a 5-millisecond frame integration time. This d.c.-coupled detector measures the intensity of the lightning and the background.

5) Broad-Band Ebert Spectrometer (BBS). This spectrometer (Fig. 12) (1/8-meter) is used to observe the lightning spectra (3 Å wavelength resolution) primarily in the near infrared. It is stepper-motor controlled and has a 5-millisecond frame time and a FOV of 15 deg. For the spring 1982 flight program, it flew in the standard configuration; for the summer 1982 flight program, it was modified by placing a fiber optic plug and image intensifier between the exit slit of the spectrometer and the photo-diode array. This increased the gain by a factor of 15,000 over the 1981 system. In addition, the modified spectrometer had its detection window increased to 3000 Å and the wavelength resolution changed to 6 Å.

6) High-Resolution Ebert Spectrometer (HRS). This one-half meter spectrometer (Fig. 13) was also used to observe the lightning spectra at 0.5 Å wavelength resolutions primarily in the near infrared. This instrument, first flown in the summer 1982 flight program, has a 5-millisecond frame time resolution and a FOV of 3 deg, and is stepper-motor-controlled over a range of 3000 Å to 10,000 Å. The sensitivity of this instrument was also increased through the use of an intensifier, as done on the broad-band spectrometer.

7) Charge Coupled Device (CCD) TV Camera. A Fairchild CCD MB 301AB TV System (Fig. 14) on loan from the USAF, Wright Aeronautical Laboratory, Wright Patterson AFB, Ohio, was installed in the U-2 to collect real-time TV images of the cloud-top structure and lightning discharges. These video

data and IRIG-B time were recorded on a VTR. The TV camera had a 12.5 mm lens (FOV of 45 deg) and selectable interference filter for flight, and looked through a window in the bottom hatch of the U-2. The filter used on the TV camera is identical to those on the OPD and OAS. The sensor of the TV camera is a CCD silicon array (488 lines, 388 pixels/line). The frame integration time was 33 milliseconds (16 milliseconds/380 x 244 fields). The frame rate was 30 frames per second, and the sync was 2:1 standard interlace.

8) Video Tape Recorder. The video recorder (Fig. 14) was a Panasonic Omnivision II VHS, NV-8400 Portable with one audio channel. Video horizontal resolution in black and white is more than 300 lines. The video record system is a two-rotary-head, helical scanning system recording at 1-5/16 in. per second. Maximum record time is 2 hours. IRIG-B time is inserted on the audio track of the recorder during the operation of the CCD TV camera.

9) Instrumentation Tape Recorders. The instrumentation rack in the upper bay of the U-2 aircraft has provisions for carrying two Sangamo Sabre 80 instrumentation recorders. These tape recorders have 14 recording tracks, and the MSFC modified Sabre 80 for the U-2 has an auto-reverse feature which enables the machine to record at 60 in. per second. The data can be recorded in the FM and direct wide band II record mode. For the spring and summer 1982 flights, only one Sabre recorder was used. To record 14 channels and achieve one hour of record time, the auto-reverse feature was not used, and the data from the sensors were recorded at 30 in. per second in one direction only. In the future, we are planning to operate in the two-recorder operational mode (Fig. 15).

10) Photography cameras. Two 70 mm Vinten Cameras were used to obtain high quality pictures of the thundercloud tops and associated lightning in both nighttime and daytime operations. Various filters were used to optimize photography based on the selected film for the particular flight period. These cameras (Fig. 16) are flown with shutters during the day operations and without shutters during the nighttime operations. Day photography f-stops were 9.5 for the black and white film and 5.6 for the color film with shutter speeds of 1/250, while night photography was taken open-shutter at 9 second intervals. The cameras each have a 1-3/4-in.-diameter Leitz lens with a FOV of 64°30′.

Based on the aircraft speed and the 9-second time interval, 92.8 percent overlap occurs on the photographs, which provides stereo imagery for both night and daytime photography. For the summer flight program one camera used Panatonic X B&W film with a Wratten 12 filter, and the other camera used Ektachrome EF Aerographic color SO 397 film. For the spring 1982 flight program, a diffraction grating was used on the SO 397 film camera for nighttime photography only. The grating was not used for the summer flight program.

11) CAMAC Crate. This equipment (Fig. 17) consists of one 8-bit transient and one 10-bit transient digitizer (each with 128 K buffer memory), a pulse code modulation (PCM) encoder, stepper motor drive, and 8085 single board microcomputer and controller. The outputs from both spectrometers and the Optical Array Sensor were digitized. The digitization rates are the same for the OAS and the spectrometers. The digitization rate provides one sample per pixel for each of the instruments. The microcomputer controls the transfer of data from the transient digitizers to the PCM encoder, and then transfers the data to the magnetic tape instrumentation recorders.

IV. DISCUSSION

A. Spring Program

The TOP 1982 spring research program began operation on May 19, 1982, and the U-2 aircraft, deployed from Ames Research Center (ARC) to Forbes Field, Topeka, Kansas, flew a total of five flights during the period of May 19, 1982 through May 27, 1982. Instrumentation personnel from MSFC and U-2 operational support personnel from ARC supported the program from Forbes Field. In addition to the MSFC and ARC personnel, research teams from New Mexico Tech (NMIT), Socorro, New Mexico and from NOAA Severe Storms Laboratory (NSSL), Norman, Oklahoma, also collected data during this period using ground-based instrumentation located at Norman, Oklahoma. Analysis of this ground-truth data will be reported in university and government reports now in preparation. Figure 18 shows some of the ground instrumentation at the Norman, Oklahoma site. Figure 19 shows the NSSL lightning ground strike detection and location network. Both day and night flights were conducted over thunderstorms in Oklahoma and Texas during which a considerable amount of data was collected. Figure 20 shows a typical cloud-to-ground strike map. Figure 21 is a more spectacular type U-2 photograph of the storm cloud and lightning. A typical sample of U-2 data for May 23, 1982, is shown in Figure 22.

During the spring flight program, a total of 4,879 pulses were recorded during the flight period (May 19 through 27, 1982). The total number of events for this flight period was 580, an event being defined for analysis purposes as a group of optical pulses which occur during a time interval of 1.46 sec. The largest event recorded showed 43 optical pulses during the defined time interval. Preliminary analysis of the slow antenna data show a total of 25 cloud-to-ground strokes that have been identified. Twelve cloud-to-ground (CG) flashes have been correlated by studying the field change wave forms taken at NSSL and the wave forms obtained by the U-2. The CG strike system at NSSL detected and located four of the 12 CG strike points. The TV image as shown before (Fig. 23) was also photographed by the Vinten camera (Fig. 24) and illustrates the kind of data which can be sampled by the TV camera system. The TV data, which can be digitized, is useful in determining cloud-top brightness and percent area illuminated by the lightning flash.

B. Summer Program

The TOP 1982 summer research program began operation on August 12, 1982. The U-2 aircraft flew a total of five flights during the period of August 12 through 19, 1982. Instrumentation personnel from MSFC supported the operation at Ames Research Center, Moffett Field, California where the U-2 is normally based for the summer program.

Only night flights were conducted over Arizona and Nevada, and again during these flights a considerable amount of data was collected. Ground truth data were obtained from the Bureau of Land Management lightning location instrumentation. Figure 25 shows the present location in the Southwest of this instrumentation. This instrumentation is mainly used by the Bureau of Land Management, Boise Interagency Fire Center, to help locate potential areas which have been struck by lightning and where forest fires could be occurring. We are using this system, since it is readily available for ground-truth data collection during our research program operation times. A typical data sample from the ΔE sensor and the WAD for August 20, 1982, is shown in Figure 26. A photograph of the lightning is shown in Figure 27.

During the summer research program, 1517 pulses were recorded during 126 events. The largest event recorded showed 43 optical pulses during the defined time interval (1.46 sec). Preliminary analysis of the slow antenna data shows a total of 39 cloud-to-ground strokes that have been identified over a span of these four flight days.

Figure 28 shows some results from the Broad Band Spectrometer data taken during the August 19, 1982 flight. Figure 29 shows the radiance and wavelength data for three frames. From this type of data, the lightning versus background signal strength values can be determined for use in design criteria for the lightning mapper. Figure 30 illustrates a TV photo of this lightning.

V. FUTURE PLANS

For the future flight programs in 1983, we are planning to use an inertial navigation system on the U-2 to provide very accurate time and position data during the flights. We are also planning to use a new and improved CAMAC system and a new pulse code modulation system to handle the data. Other experiments planned for 1984, which are now in the development stage, are a small RF sensor package and an improved film camera or TV system.

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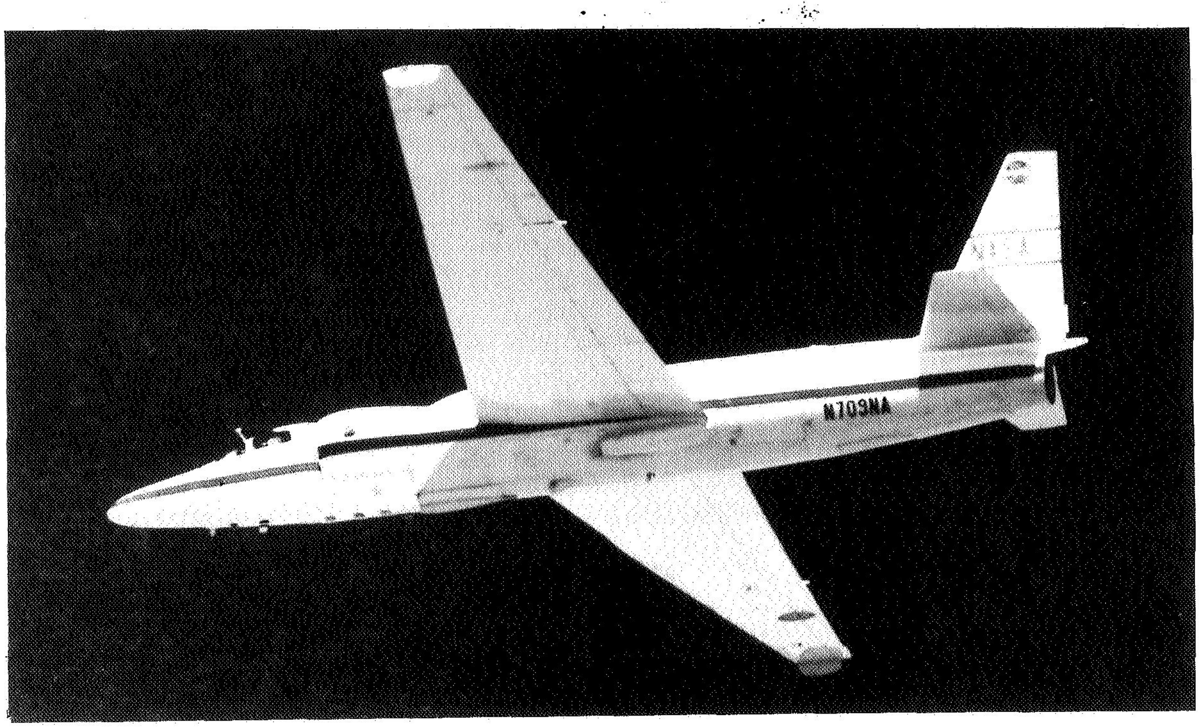


Figure 1. NASA U-2 High Altitude Research Aircraft.

U-2/THUNDERSTORM OVERFLIGHT PROGRAM (TOP)

OBJECTIVES :

- UNDERSTAND THE RELATIONSHIPS BETWEEN CONVECTIVE STORMS AND ATMOSPHERIC ELECTRICAL PHENOMENA
- PROVIDE DATA ON CLOUD CONVECTIVE MOTIONS, AND THE NUMBER, DURATION, AND FLASH INTENSITY OF LIGHTNING DURING THE DAY AND NIGHT-TIME
- PROVIDE DATA ON CLOUD TOP BRIGHTNESS AND LIGHTNING FREQUENCY AND INTENSITIES FOR SENSOR DEVELOPMENT AND DESIGN CRITERIA FOR THE SATELLITE LIGHTNING MAPPER PROGRAM

SCIENTIFIC INVESTIGATORS :

- DR. BERNARD VONNEGUT - SUNYA
- DR. R. ORVILLE - SUNYA
- MR. O. H. VAUGHAN, JR. - NASA/MSFC
- DR. H. CHRISTIAN - NASA/MSFC
- MR. R. L. FROST - NASA/MSFC
- DR. MARX BROOK - NMIT
- DR. D. RUST - NOAA/NSSL

Figure 2. Objective and Scientific Investigators.

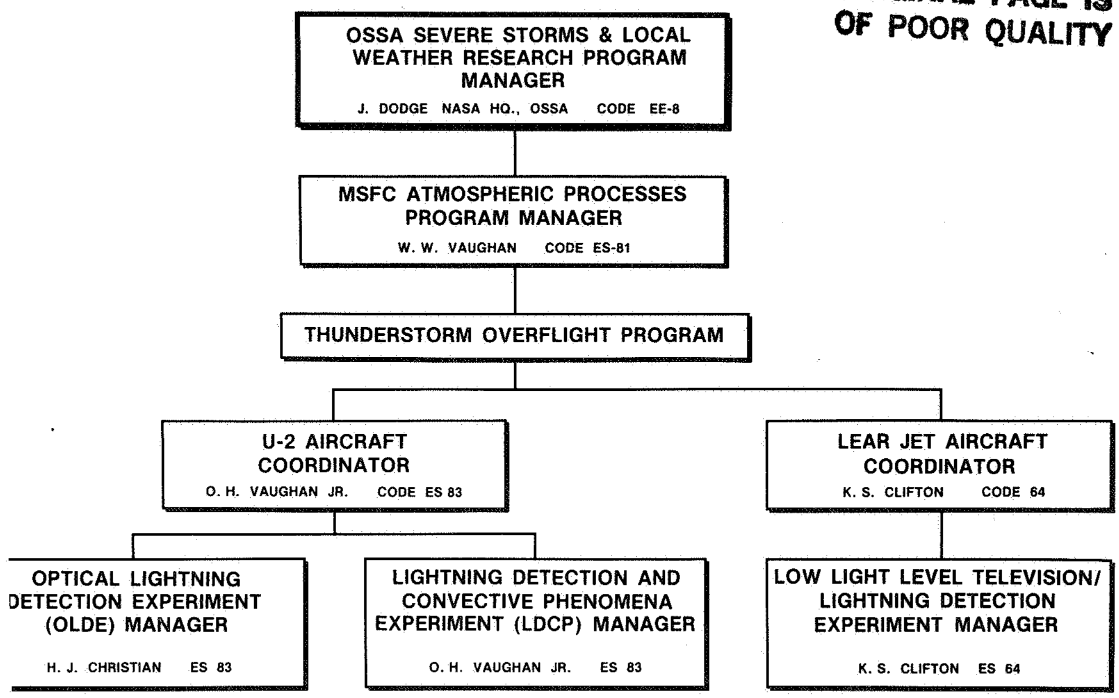


Figure 3. Project Management for Thunderstorm Overflight Program "TOP 1981".

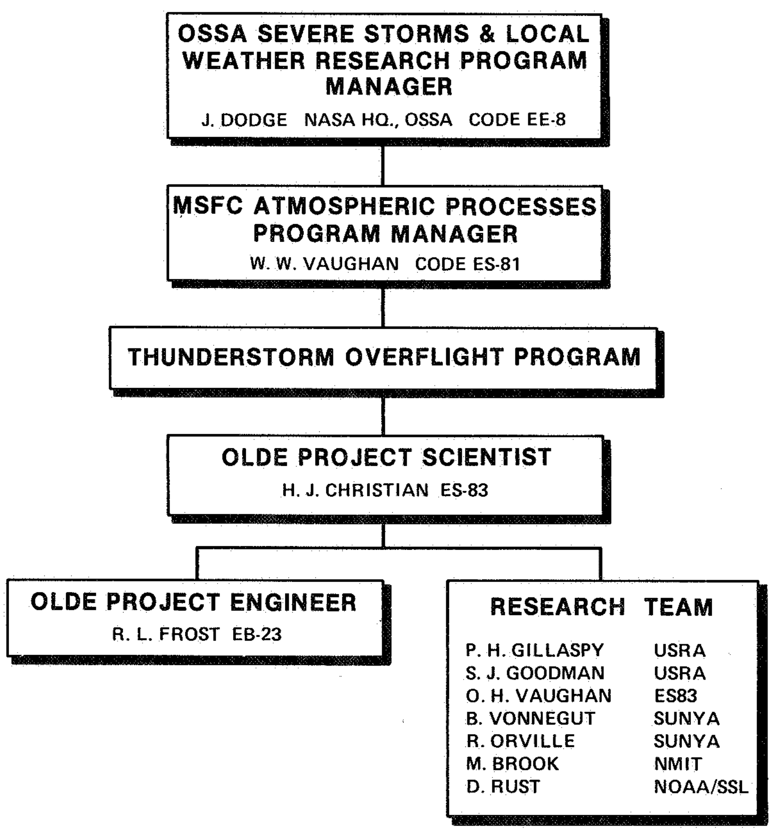


Figure 4. Project Management for Optical Lightning Detection Experiment (OLDE) for "TOP 1982."

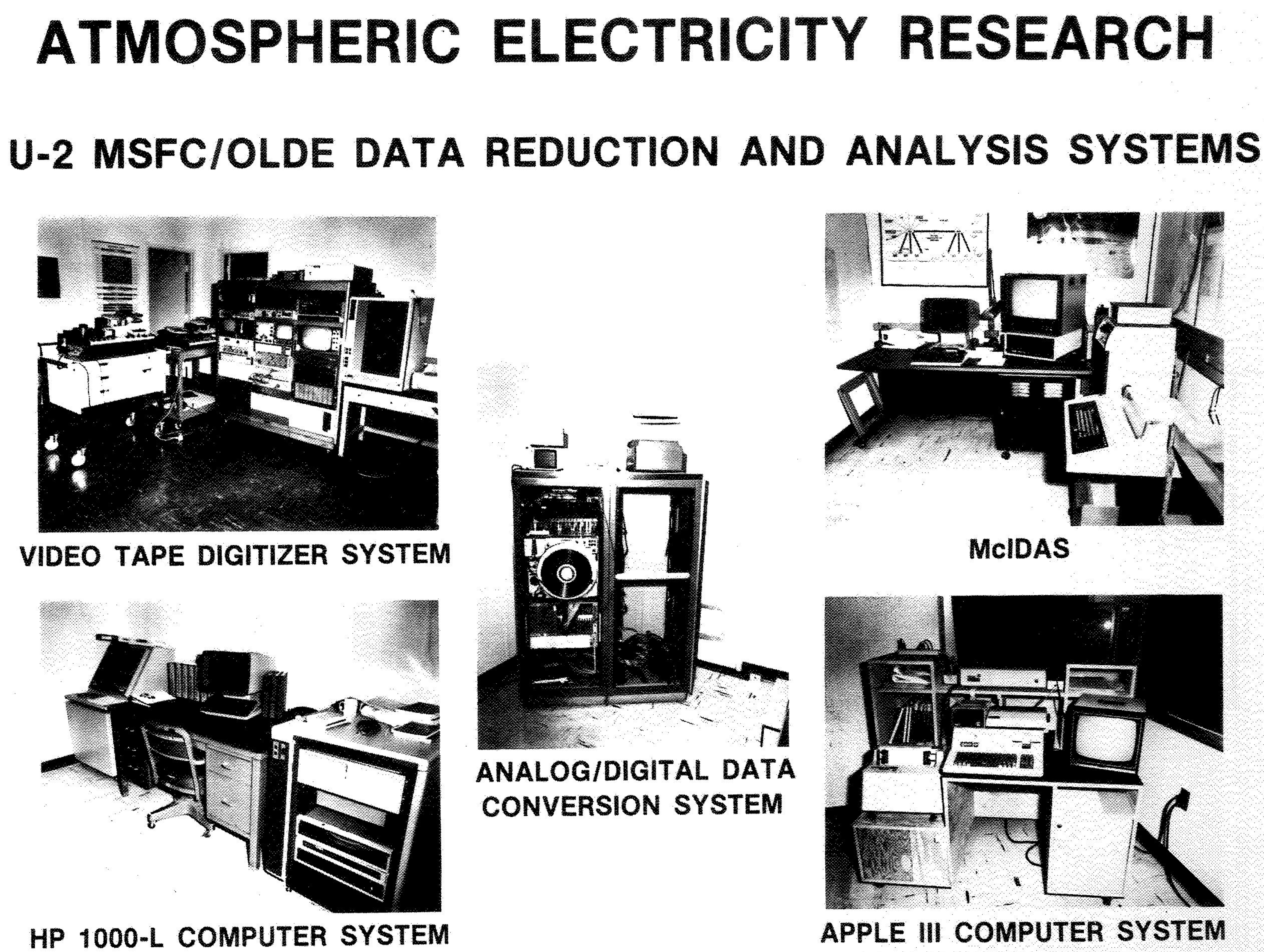


Figure 5. Data Reduction and Analysis Hardware for U-2/MSFC OLDE.

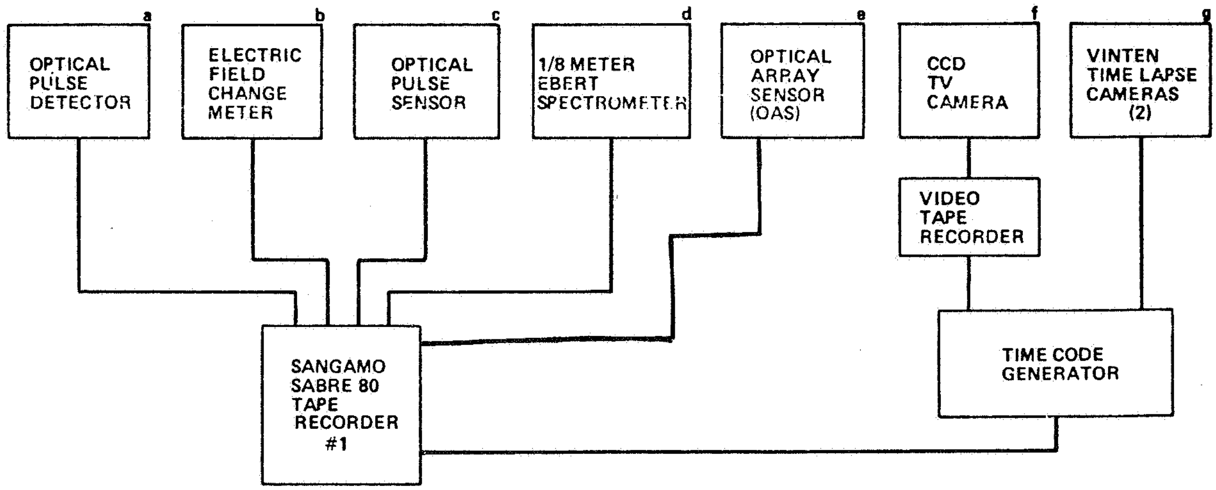


Figure 6A. Block Diagram of U-2 Aircraft Lightning Instrumentation for Spring 1982.

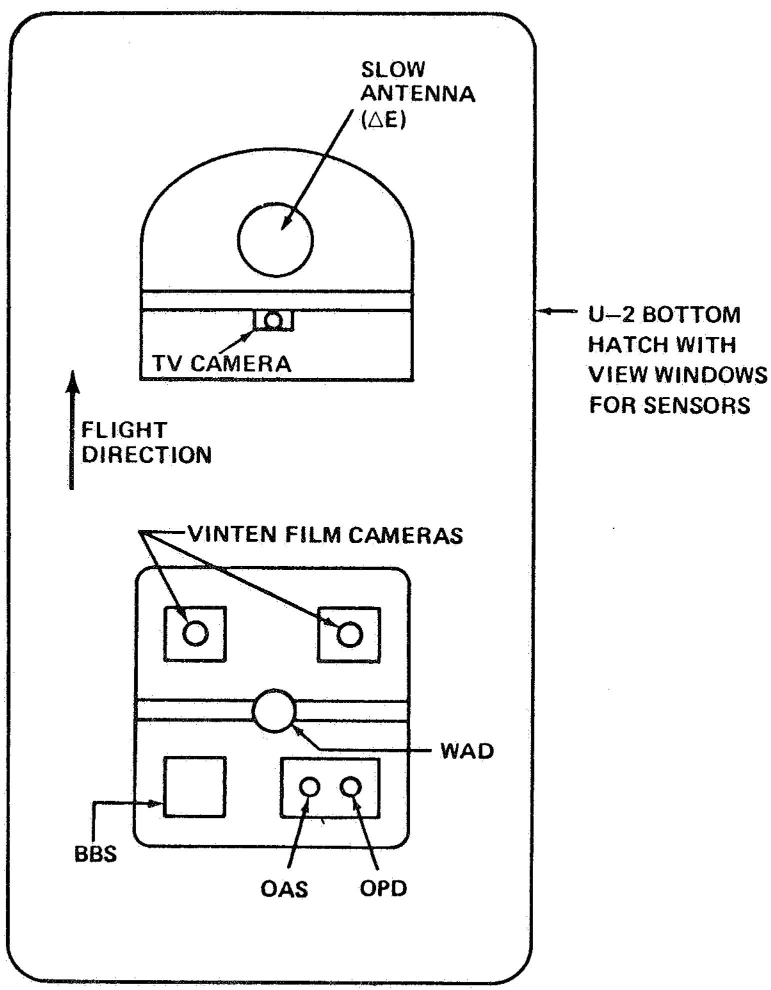


Figure 6B. Schematic Layout of Various Sensors for Atmospheric Electricity Research Program/"TOP 1982" Spring Program.

U-2/THUNDERSTORM OVERFLIGHT PROGRAM (TOP)

SPRING "82" INSTRUMENTATION

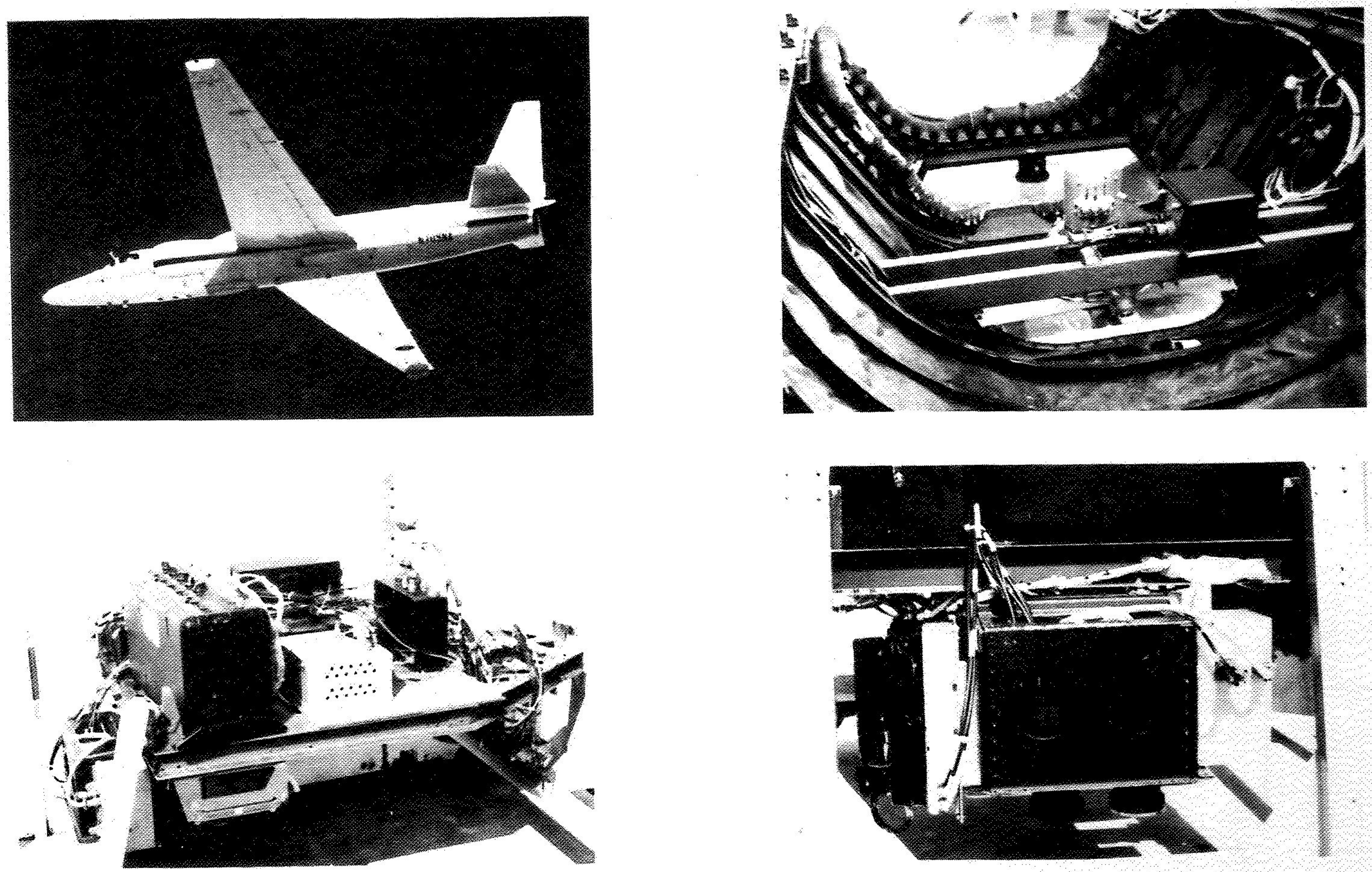


Figure 7. Pallet and Hatch Mounted Instrumentation for Spring 1982.

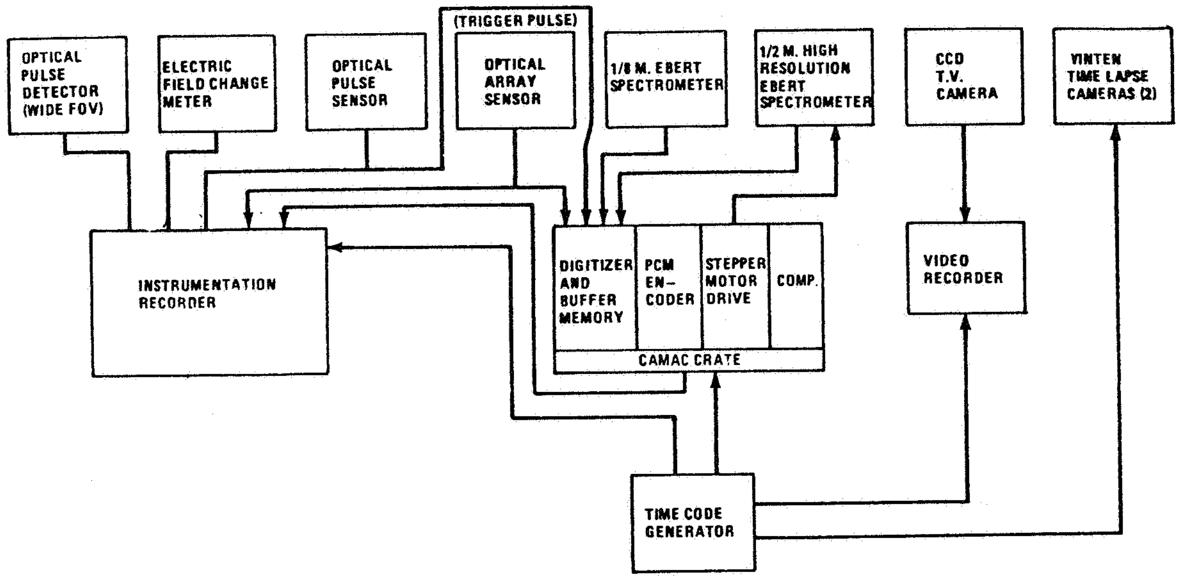


Figure 8A. Block Diagram for U-2 Aircraft Lightning Instrumentation for Summer 1982.

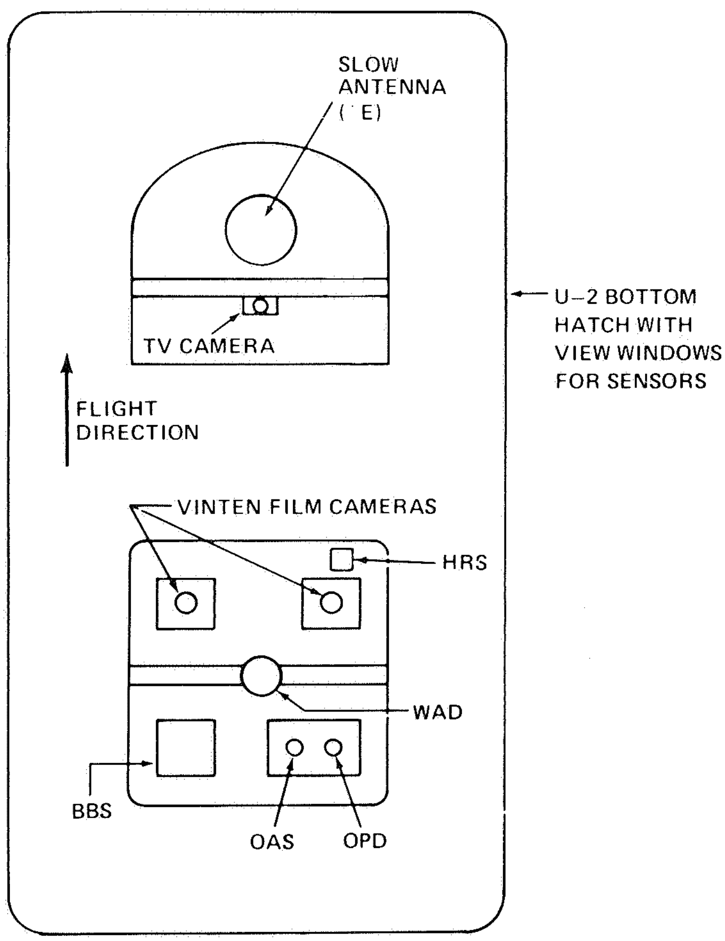


Figure 8B. Schematic Layout of Various Sensors for Atmospheric Electricity Research Program/"TOP 1982" Summer Program.

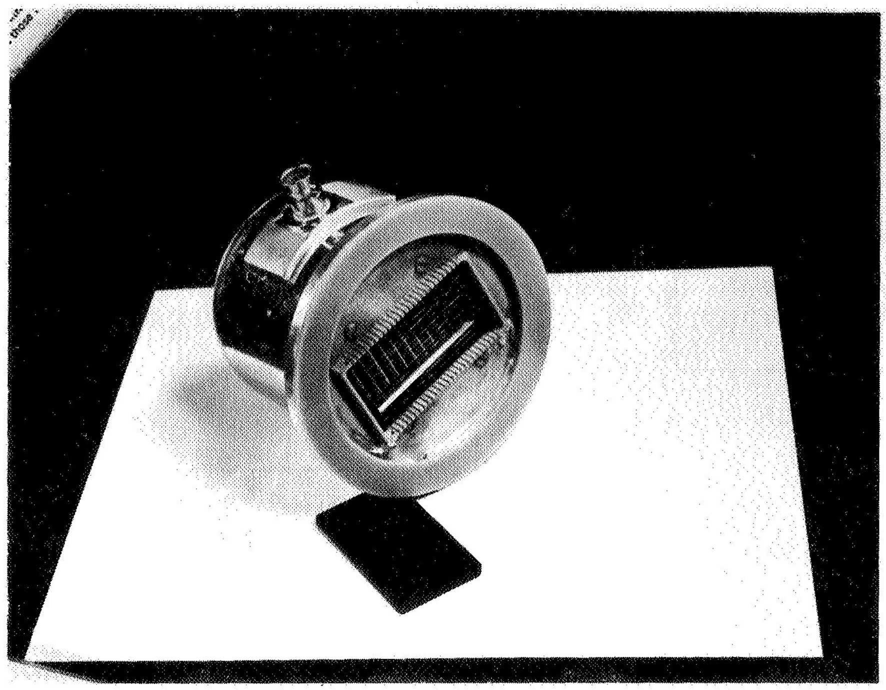
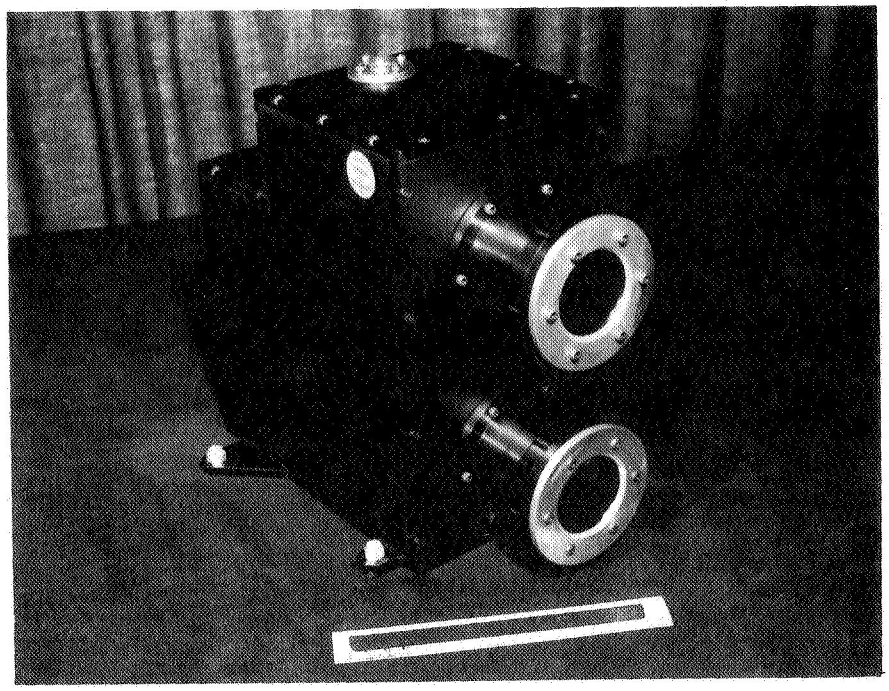
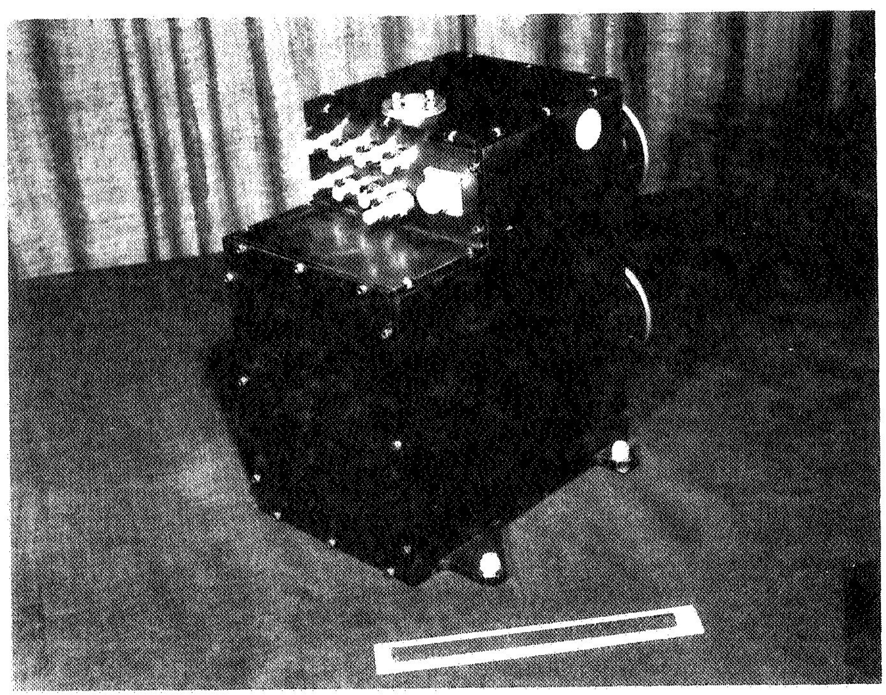


Figure 9. Wide Angle Optical Pulse Detector (WAD).

Figure 10. Electric Field Change Meter (ΔE).



Front View



Rear View

Figure 11. Optical Array Sensor.

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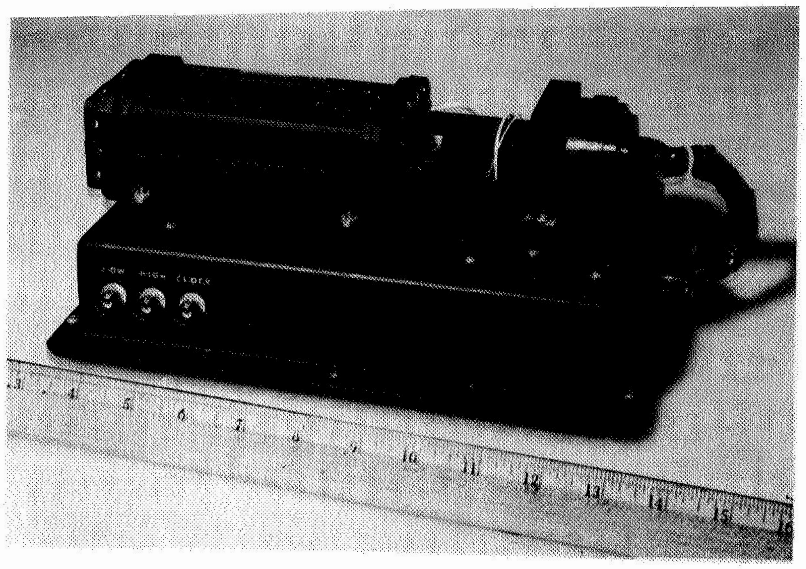

Figure 12. Broad Band Ebert Spectrometer.

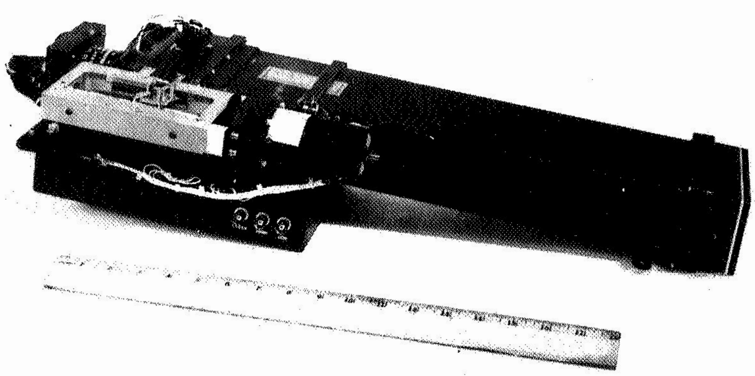

Figure 13. High Resolution Ebert Spectrometer.

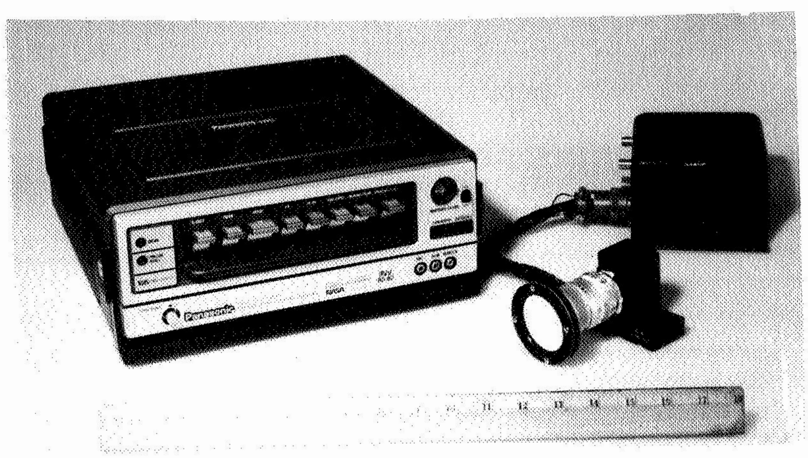

Figure 14. CCD Camera, Recorder, and Power Supply.

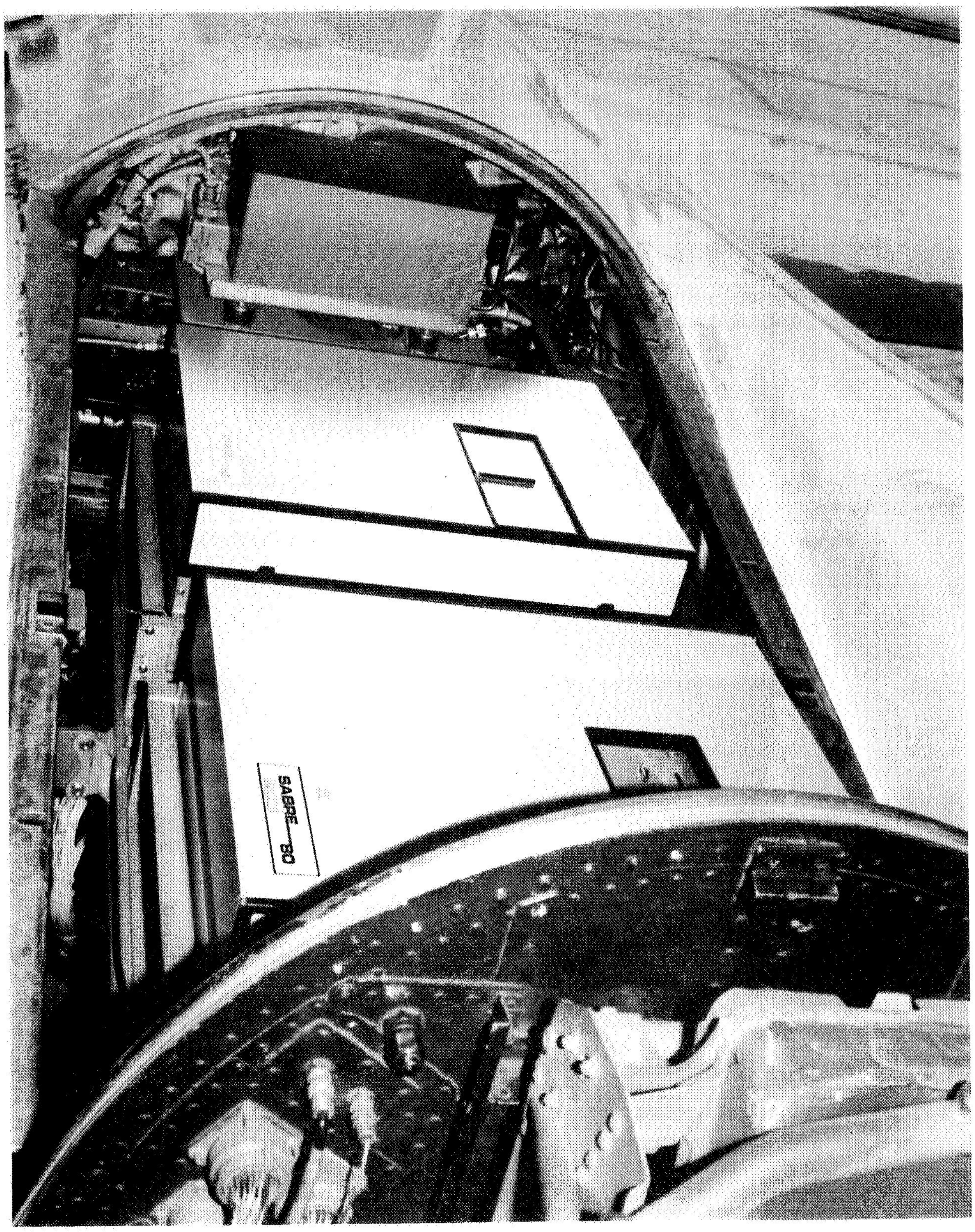

Figure 15. Instrumentation Tape Recorders – Two-Mode Operational Configuration.

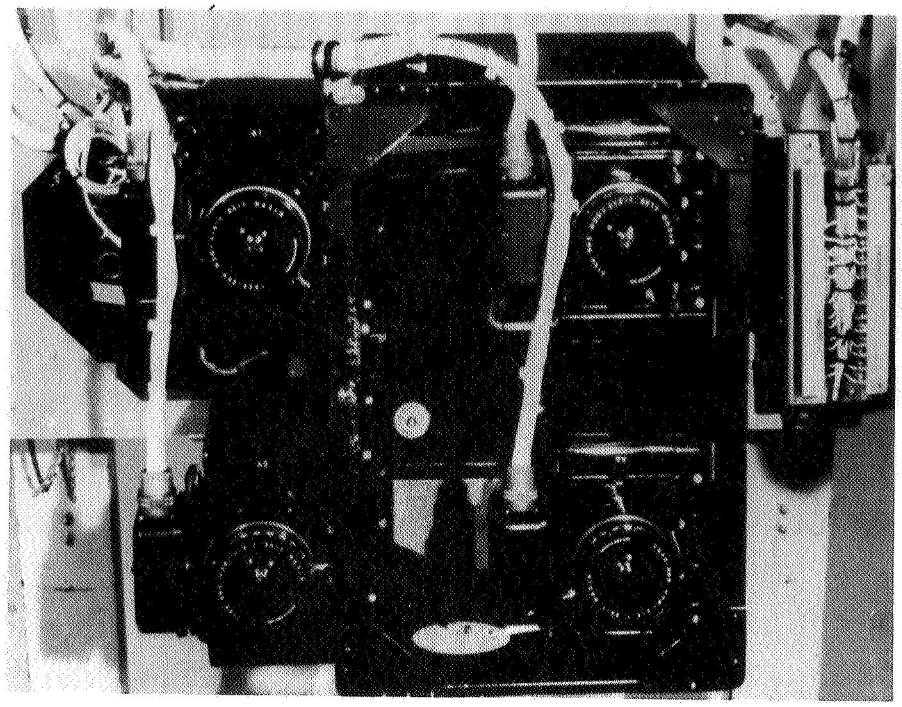

Figure 16. Vinten Camera – Four Mode Operational Configuration (Basic).

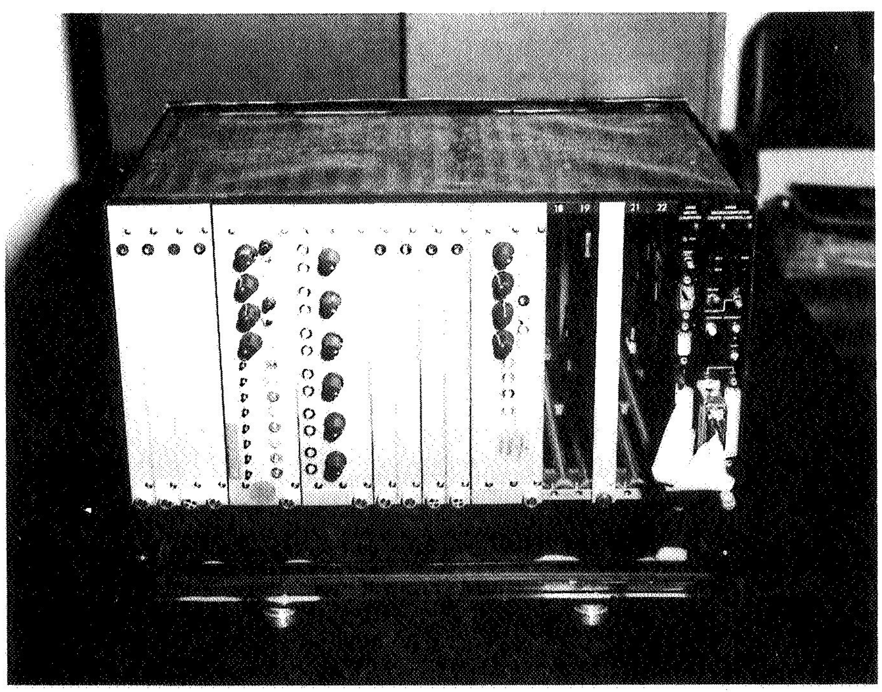

Figure 17. CAMAC Crate Configuration for Summer 1982 Flights.

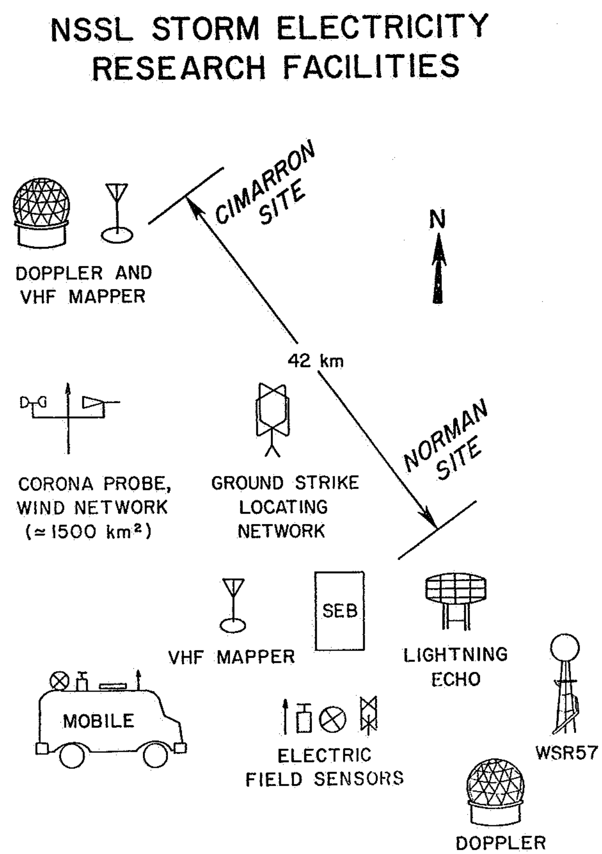

Figure 18. Storm Electrical Research Facilities at Norman, Oklahoma, Severe Storms Research Laboratory, NOAA.

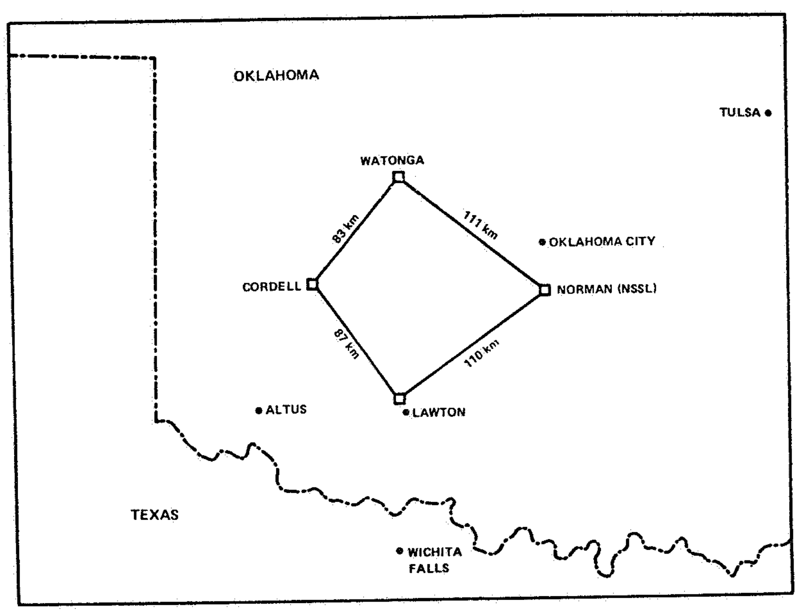

Figure 19. Lightning Locating Ground Instrumentation Network in Oklahoma.

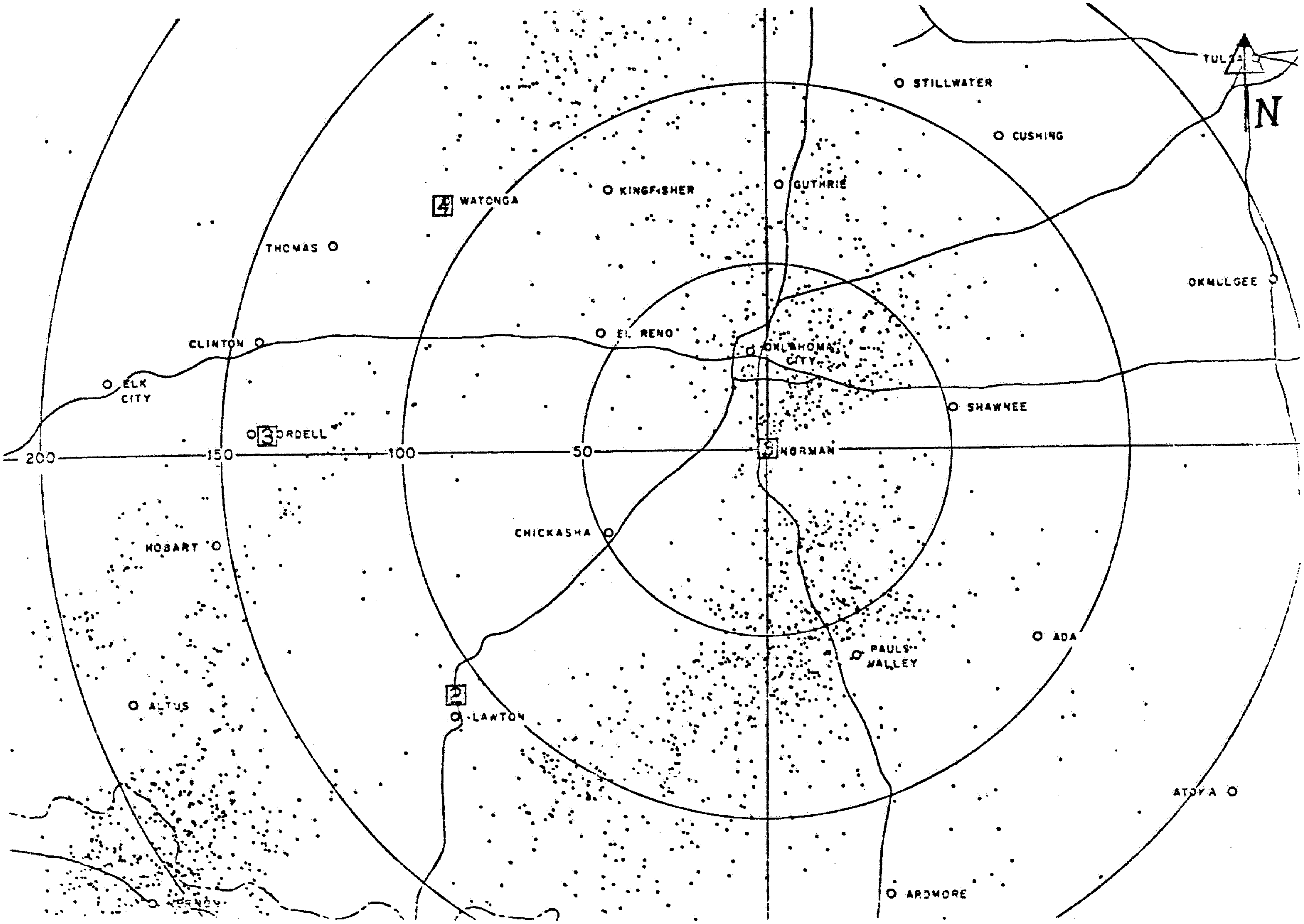

Figure 20. Typical Lightning Cloud to Ground Strike Mapping as Produced by Ground Strike Lightning Detection Network.

Figure 21. Typical Vinten Camera Photo of Cloud and Lightning at GMT 024709 May 23, 1982.

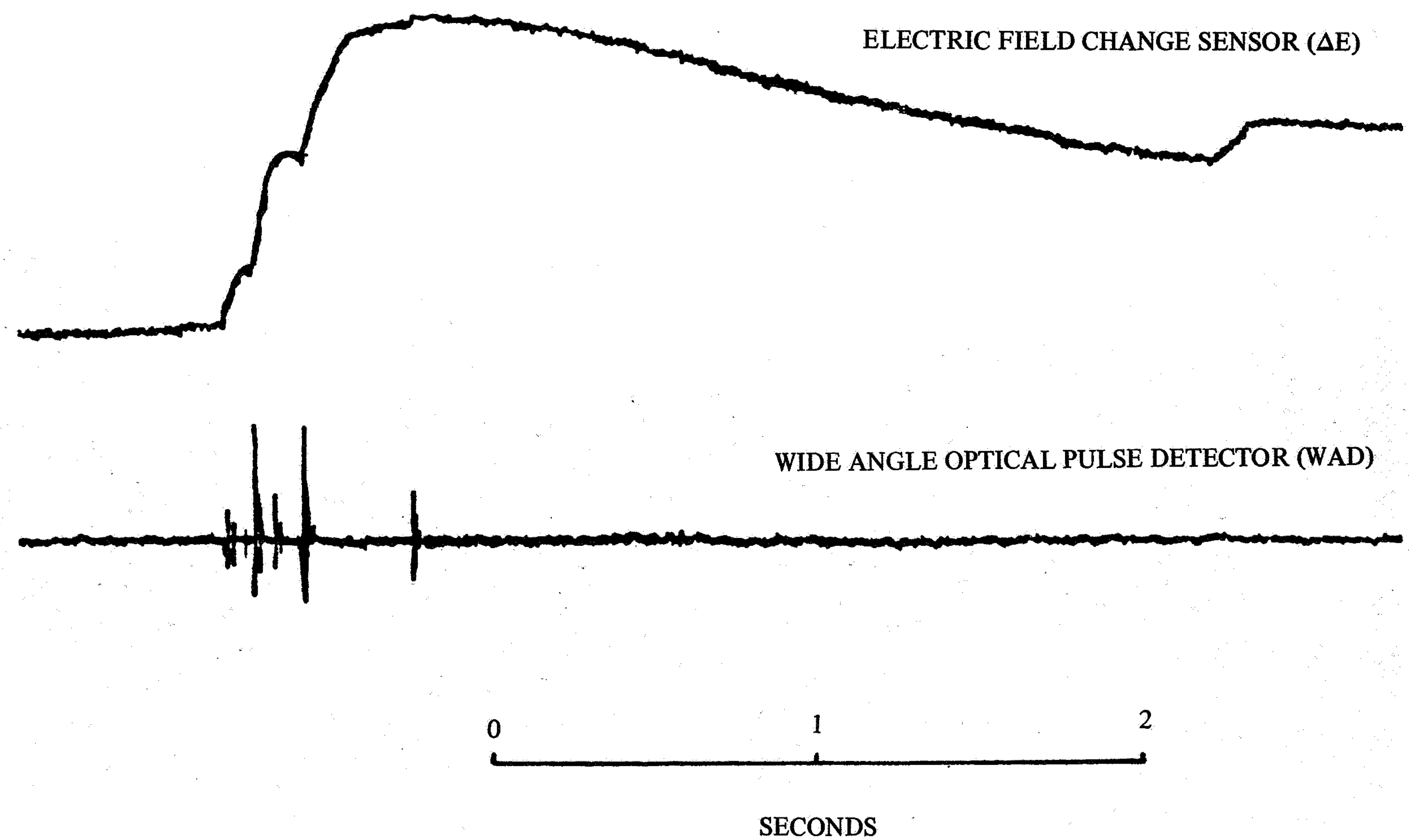

Figure 22. Wide Angle Optical Pulse Detector (WAD) and Electric Field Change Data (ΔE) for May 23, 1982 GMT 030658.

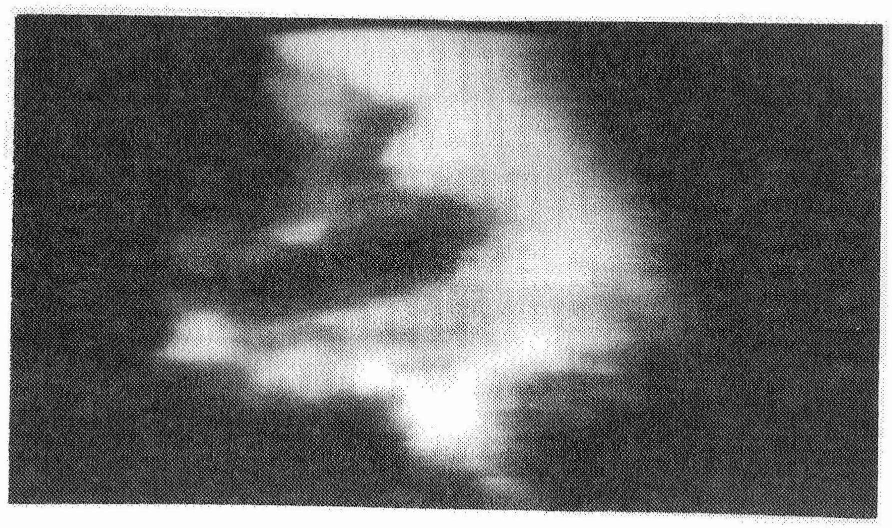

Figure 23. TV Image of Cloud and Lightning at GMT 030658 May 23, 1982.

Figure 24. Photo of Same Cloud and Lightning from Vinten Camera at GMT 030709 May 23, 1982.

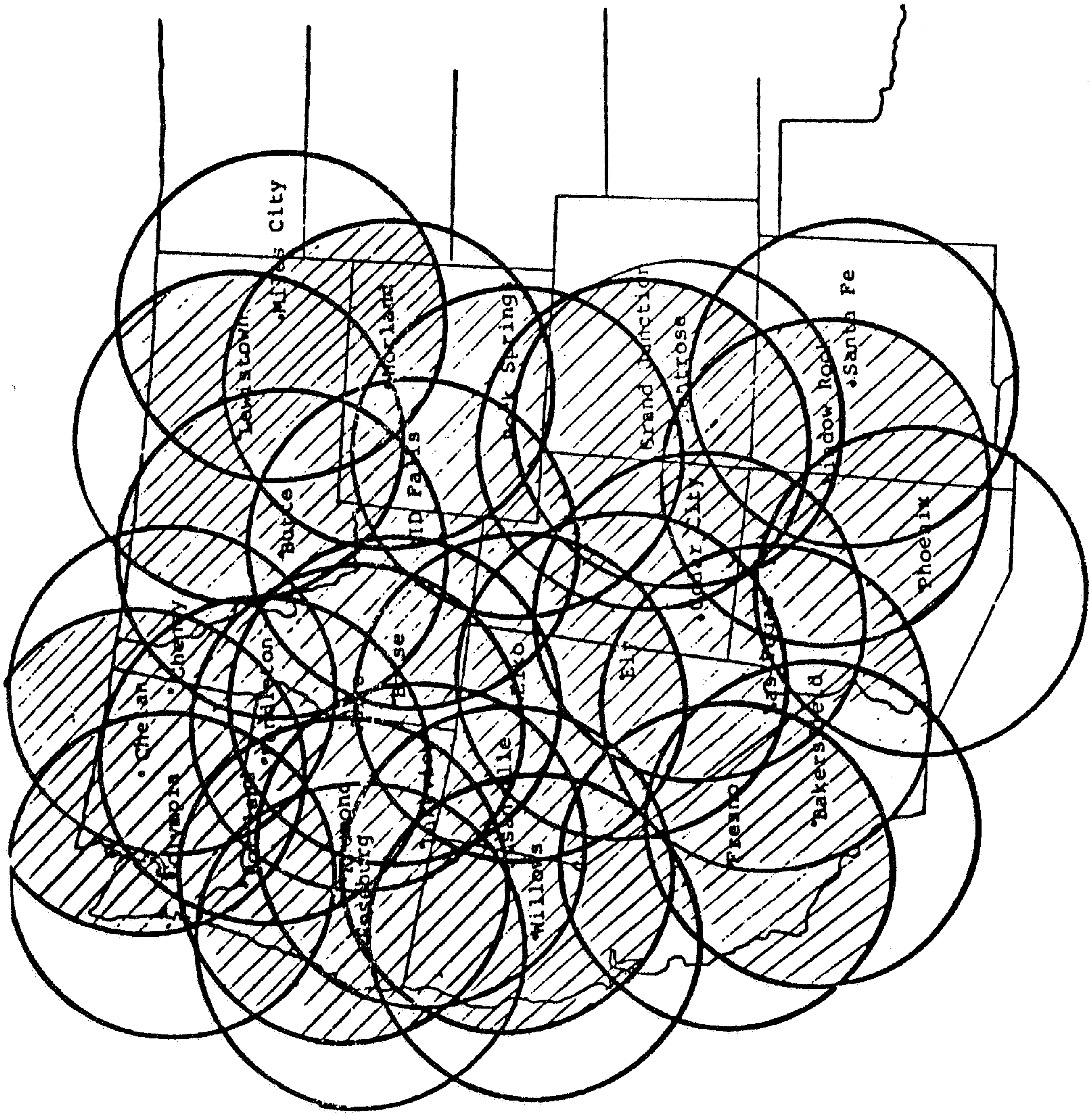

Figure 25. Bureau of Land Management Lightning Location Instrumentation.

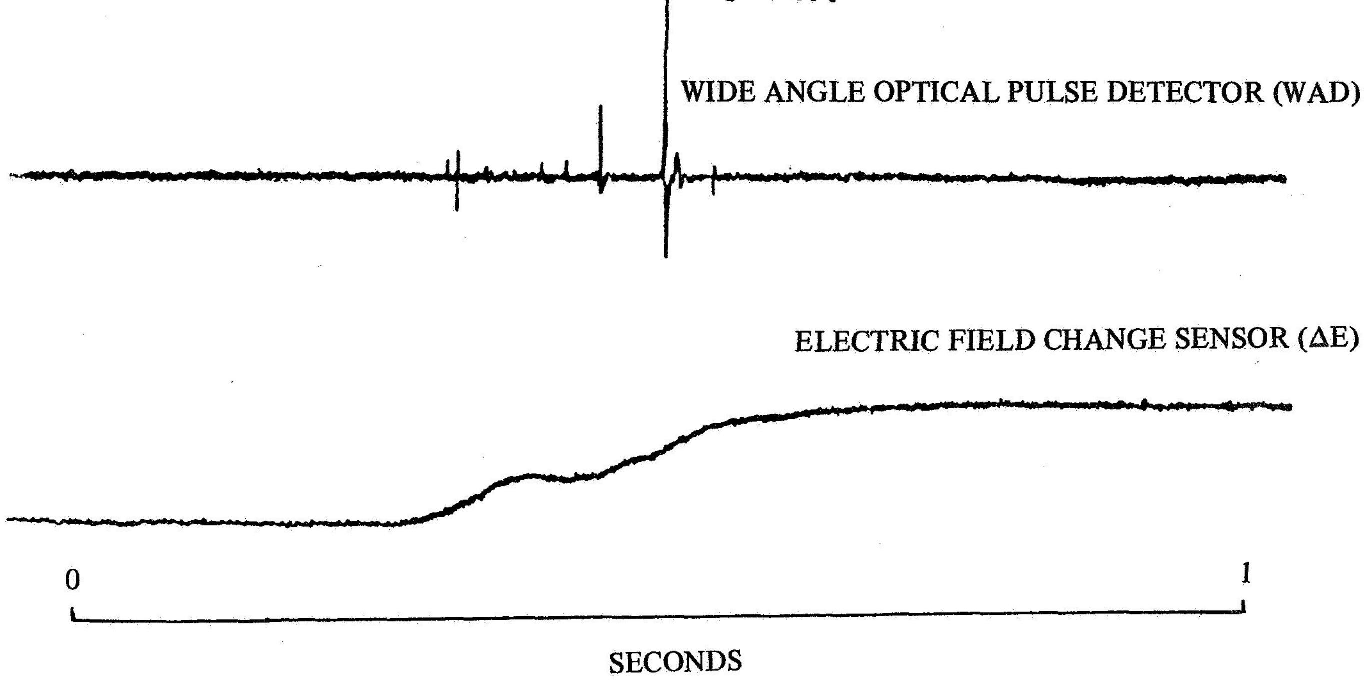

Figure 26. Wide Angle Optical Pulse Detector (WAD) and Electric Field Change Data (ΔE) for August 20, 1983 GMT 031111.

Figure 27. Typical Vinten Photo of Lightning at GMT 031111, August 20, 1982.

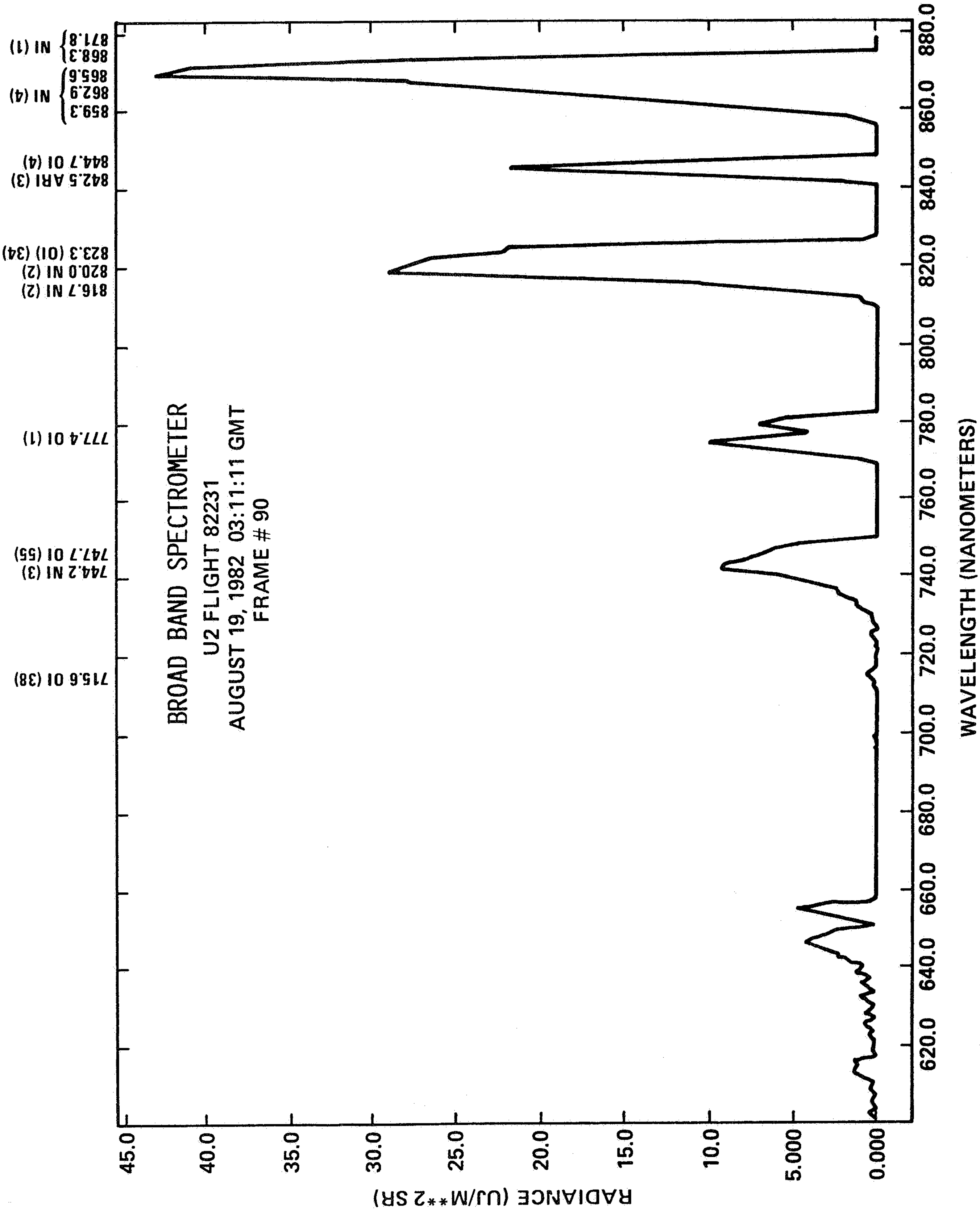

Figure 28. Radiance versus Wavelength Data from Broad Band Spectrometer Frame 90.

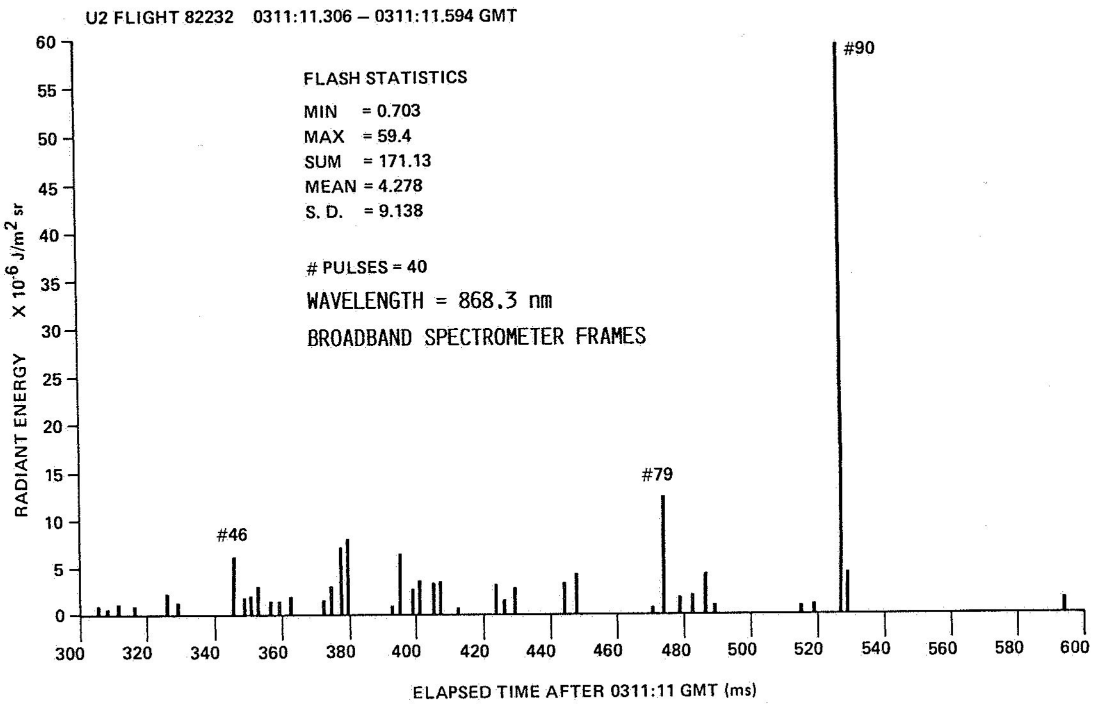

Figure 29. Flash Statistics and Pulse Data from Broad Band Spectrometer Radiant Energy versus Lapsed Time.

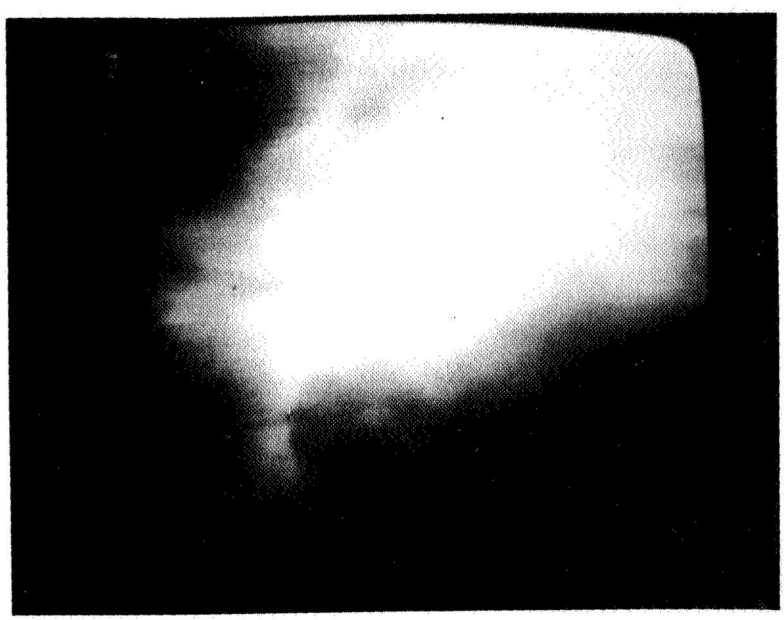

Figure 30. TV Photo of Lightning at GMT 031111, August 20, 1982.

APPENDIX A

DAYTIME VINTEN PHOTOGRAPHY

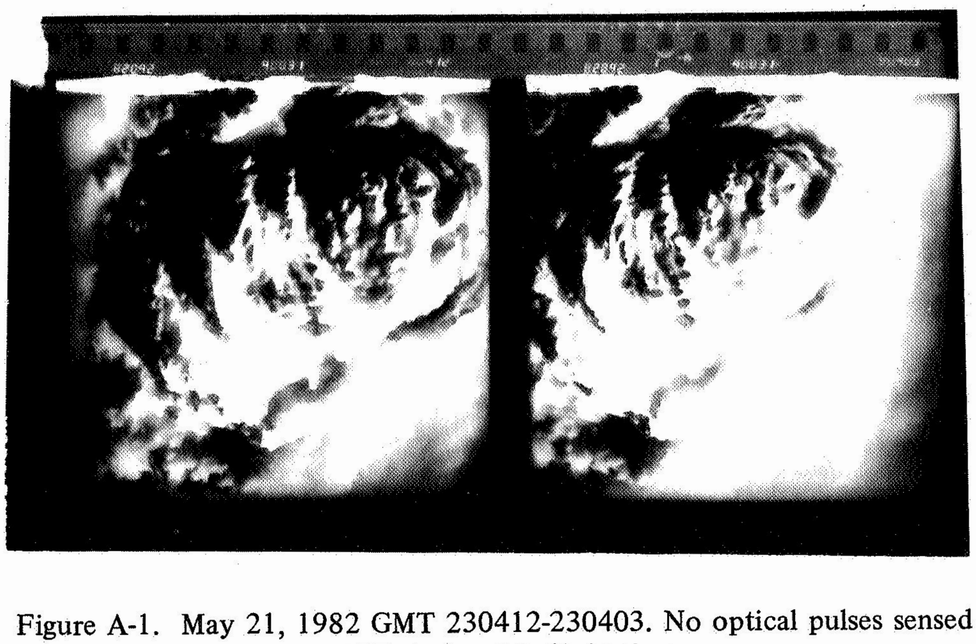

Figure A-1. May 21, 1982 GMT 230412-230403. No optical pulses sensed by OPD during this flight time.

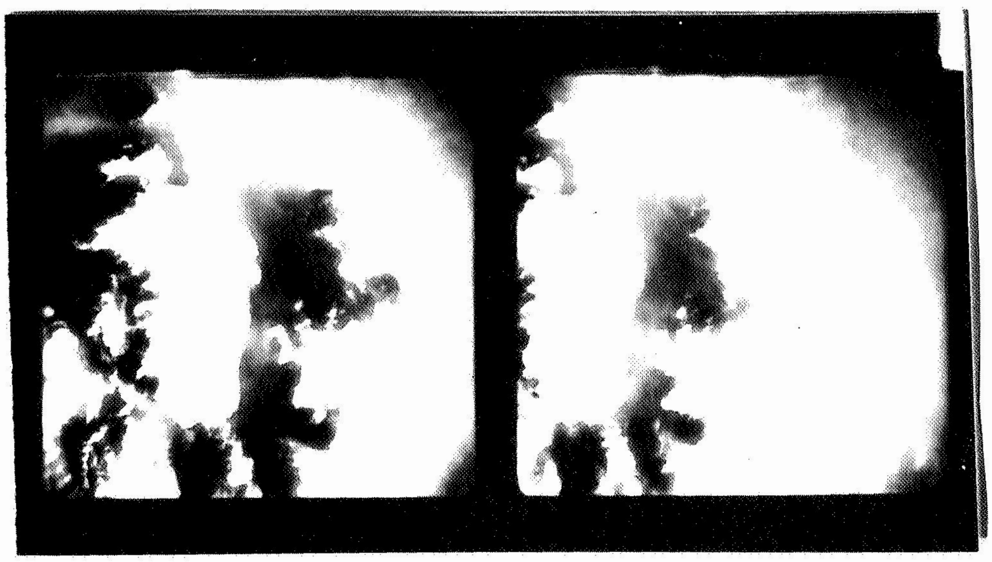

Figure A-2. May 21, 1982 GMT 234628-234618. 11 optical pulses sensed by the OPD (time period of 2.92 sec, 2 events) during this flight time.

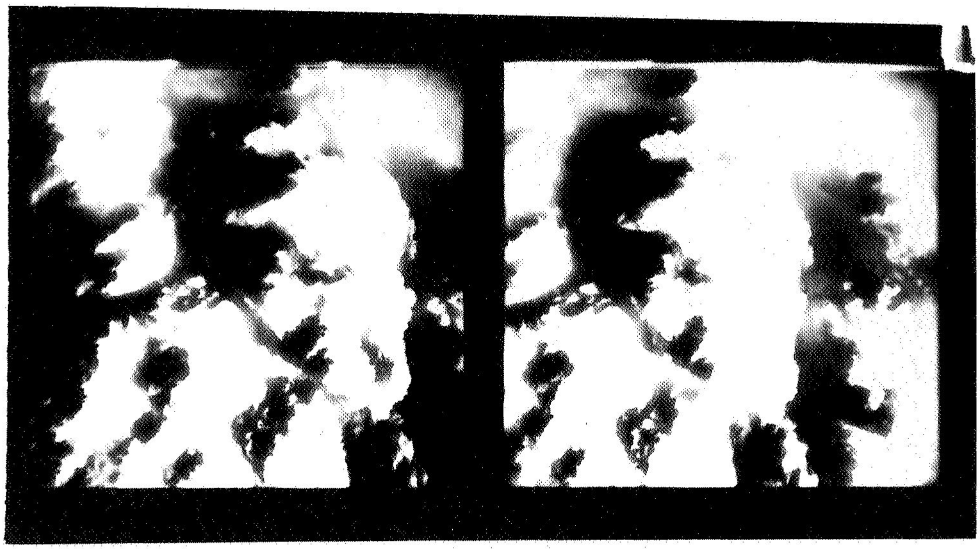

Figure A-3. May 21, 1982 GMT 234646-234631. 42 optical pulses sensed by the OPD (time period of 7.3 sec, 5 events) during that flight time.

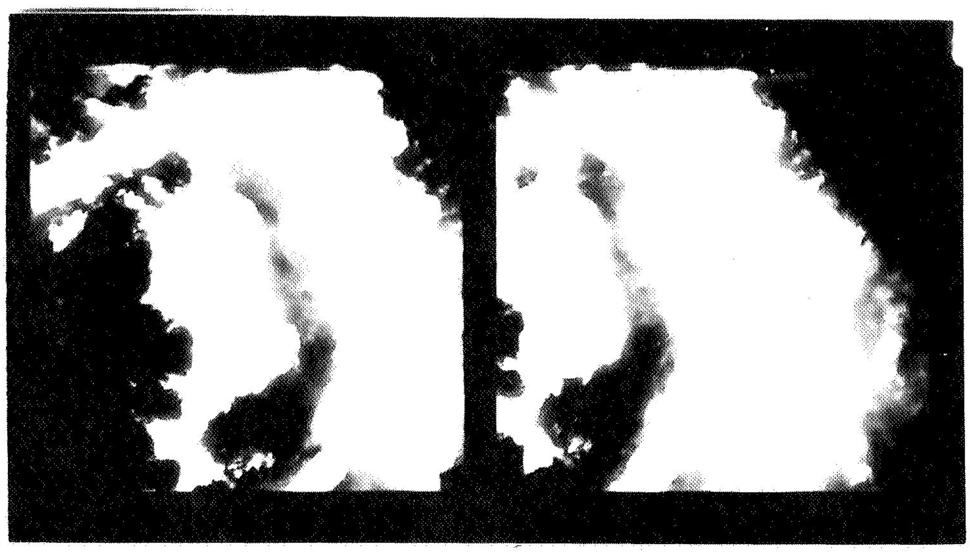

Figure A-4. May 21, 1982 GMT 235551-235542. 51 optical pulses sensed by the OPD (time period of 7.3 sec, 5 events) during this flight time.

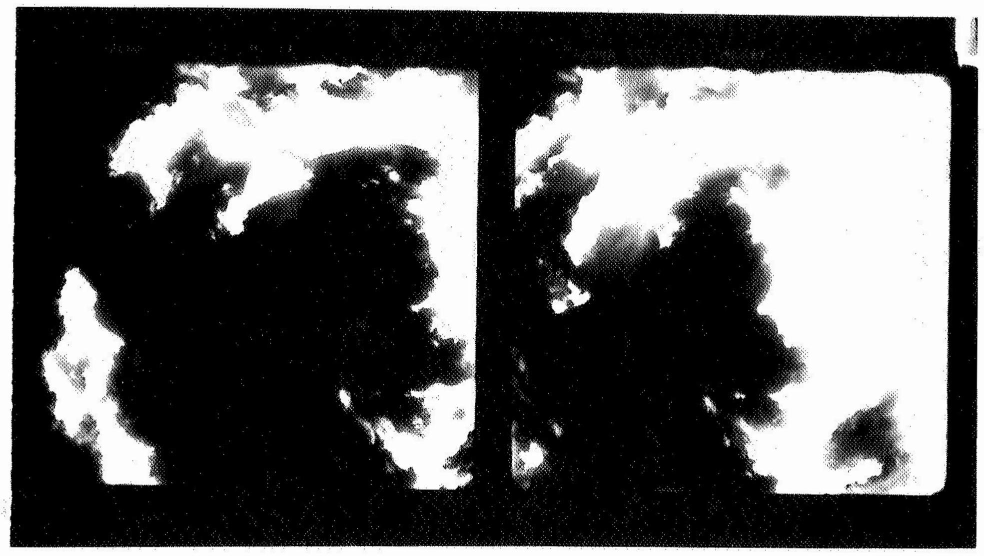

Figure A-5. May 21, 1982 GMT 235604-035600. 14 optical pulses sensed by OPD (time period 1.46 sec, 1 event) during this flight time.

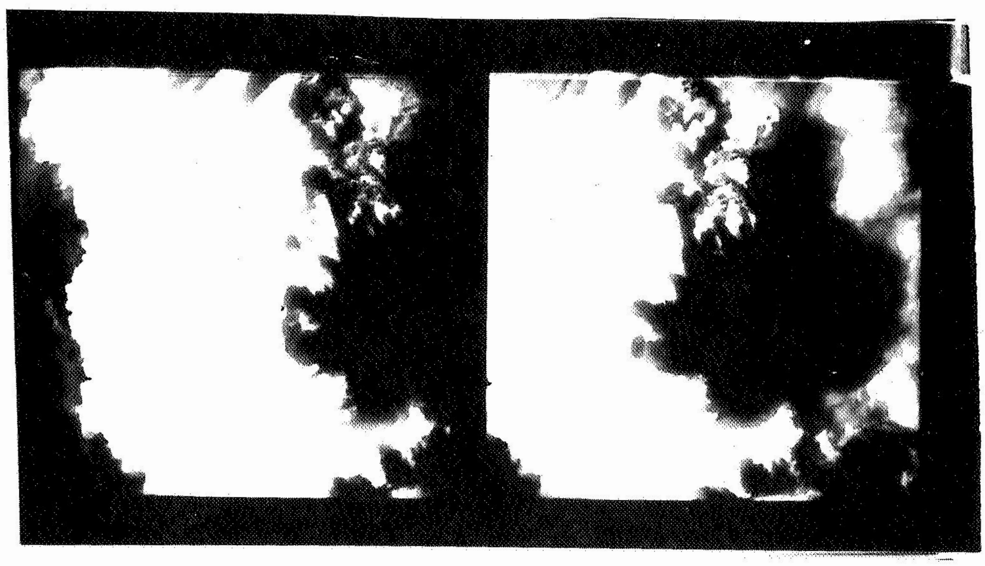

Figure A-6. May 22, 1982 GMT 000514-000505. 8 optical pulses sensed by OPD (time period 2.92 sec, 2 events) during this flight time.

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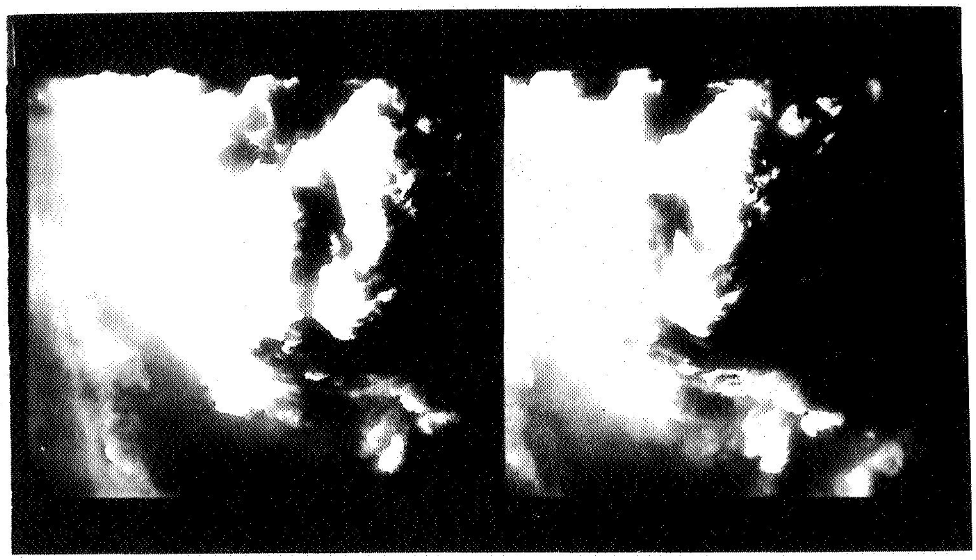

Figure A-7. May 22, 1982 GMT 001134-001130. 11 optical pulses sensed by OPD (time period 1.46 sec, 1 event) during this flight time.

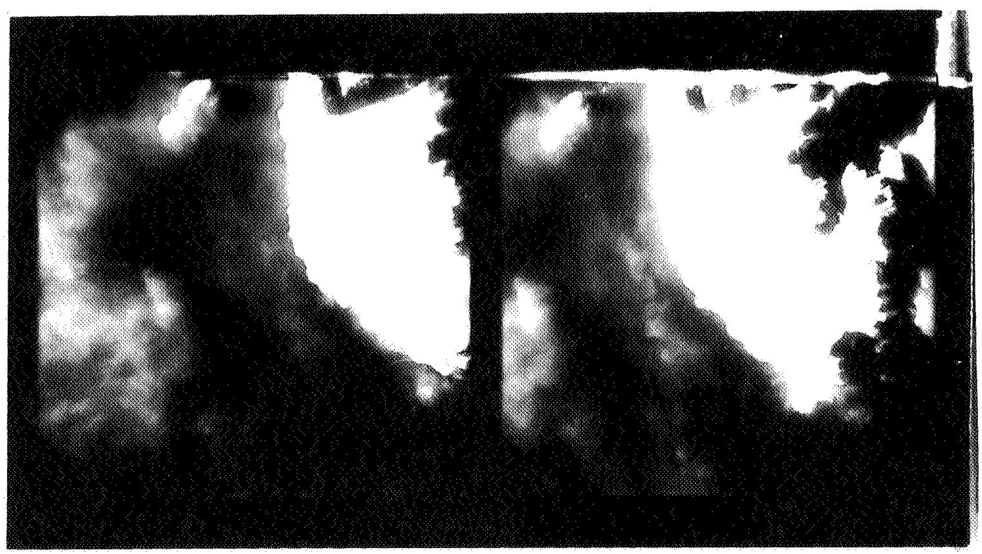

Figure A-8. May 22, 1982 GMT 001158-001130. 53 optical pulses sensed by OPD (time period 5.84 sec, 4 events) during this flight.

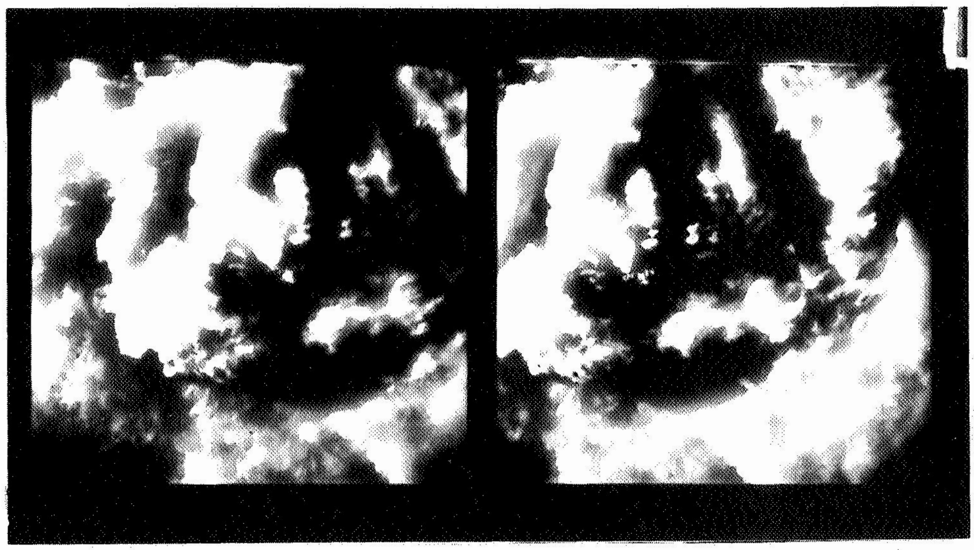

Figure A-9. May 22, 1982 GMT 001648-001634. 48 optical pulses sensed by OPD (time period 4.38 sec, 3 events) during this flight time.

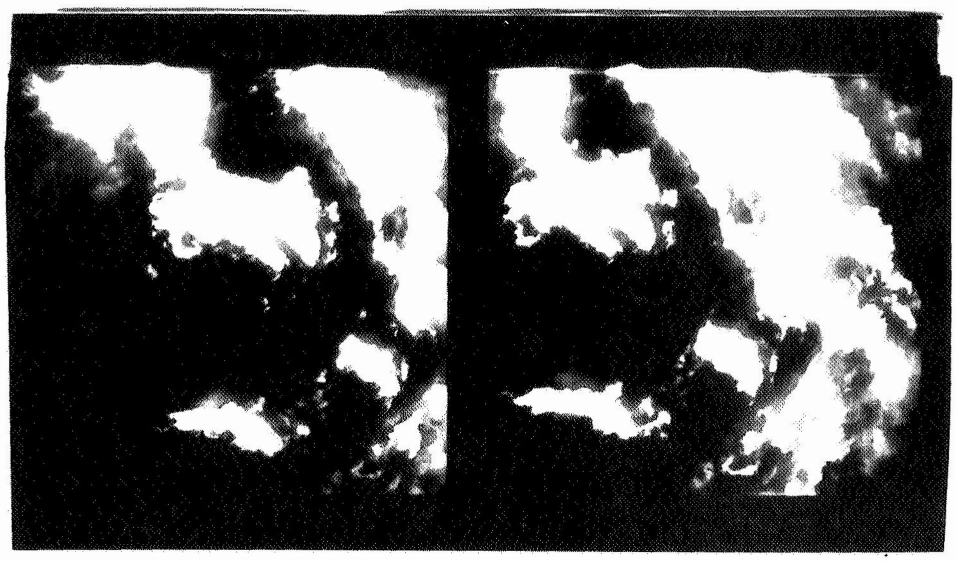

Figure A-10. May 22, 1982 GMT 002332-002323. No optical pulses sensed by OPD during this flight time.

APPENDIX B

NIGHTTIME VINTEN PHOTOGRAPHY

Figure B-1. August 19, 1982, GMT 030909, Flight No. 4, Cloud Top/Lightning Flash.

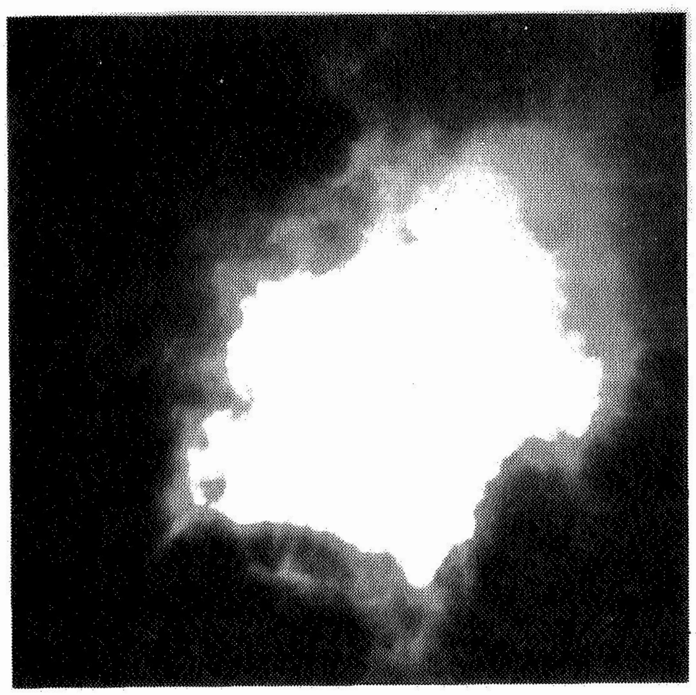

Figure B-2. August 19, 1982, GMT 032129, Flight No. 4, Cloud Top/Lightning Flash.

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Figure B-3. August 19, 1982, GMT 033040, Flight No. 4, Cloud Top/Lightning Flash.

Figure B-4. August 19, 1982, GMT 033058, Flight No. 4, Cloud Top/Lightning Flash.

Figure B-5. August 19, 1982, GMT 034159, Flight No. 4, Cloud Top/Lightning Flash.

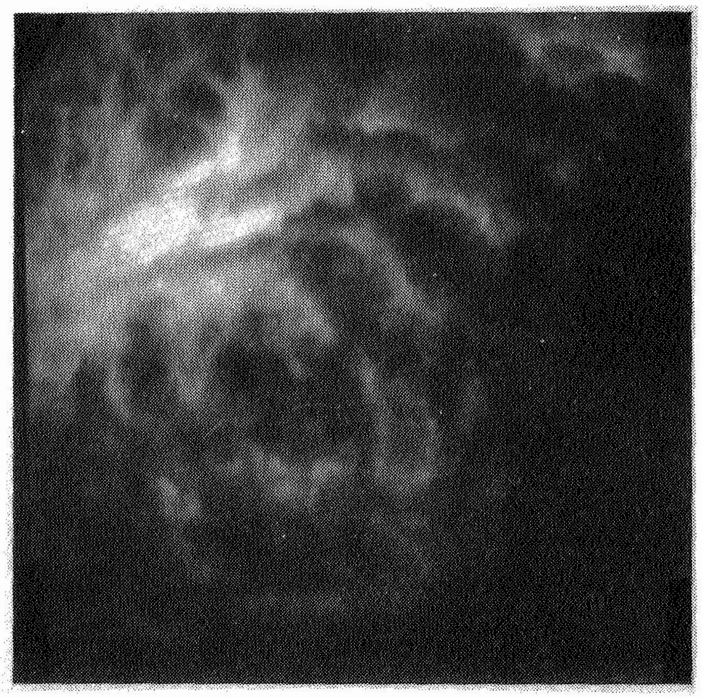

Figure B-6. August 19, 1982, GMT 034311, Flight No. 4, Cloud Top/Lightning Flash.

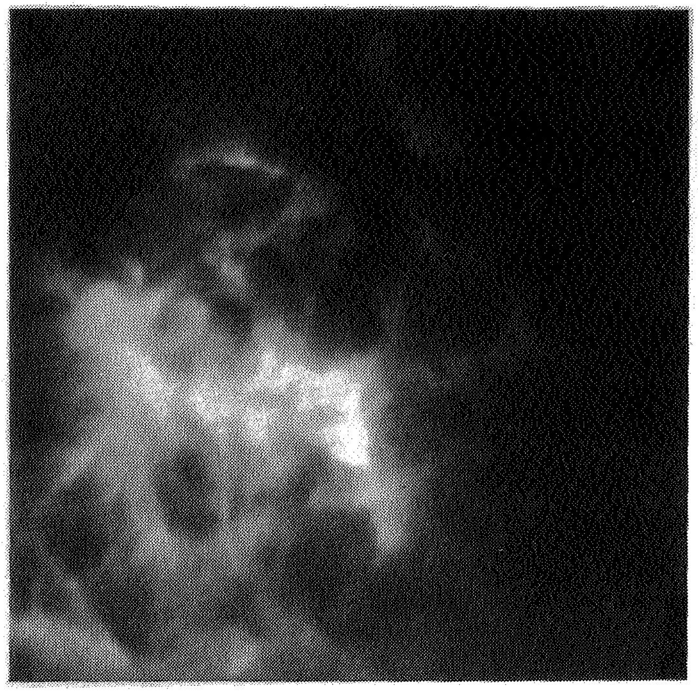

Figure B-7. August 19, 1982, GMT 034355, Flight No. 4, Cloud Top/Lightning Flash.

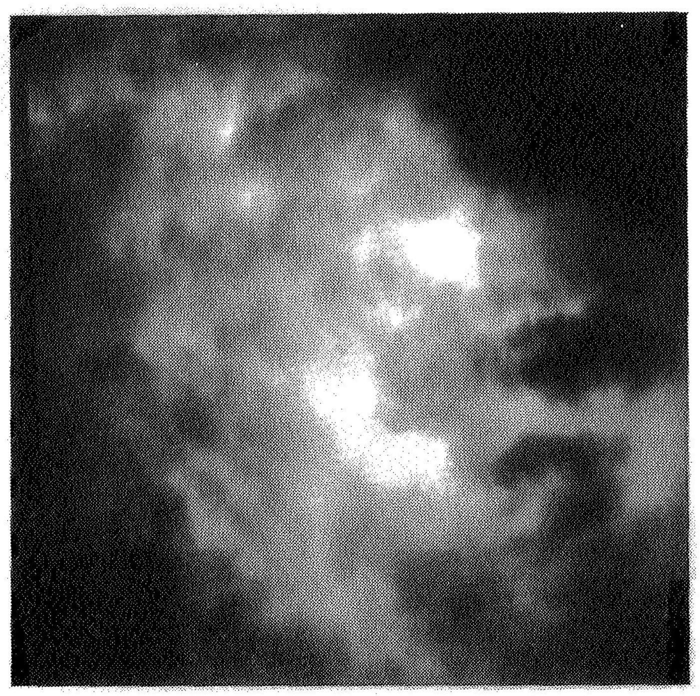

Figure B-8. Ausugt 19, 1982, GMT 035207, Flight No. 4, Cloud Top/Lightning Flash.

Figure B-9. August 20, 1982, GMT 031959, Flight No. 5, Cloud Top/Lightning Flash.

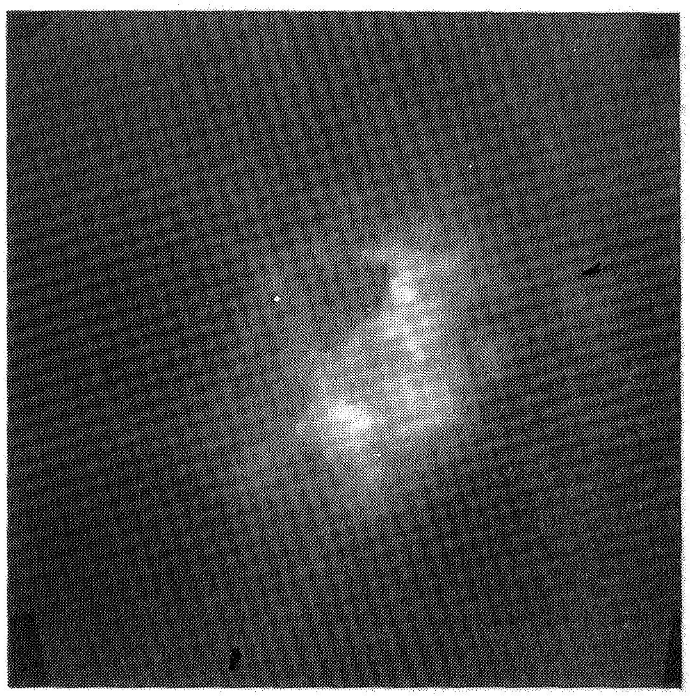

Figure B-10. August 20, 1982, GMT 032102, Flight No. 5, Cloud Top/Lightning Flash – Cloud to ground stroke with five return strokes as per NSSL data.

APPENDIX C

SUPPORTING ORGANIZATIONS AND PERSONNEL FOR THE THUNDERSTORM OVERFLIGHT PROGRAM

NASA Headquarters
Washington, D.C.

J. Dodge, FTS 755-8596
(202) 755-8596

NASA MSFC
Huntsville, Alabama

W. Vaughan, Mail Code ED41, FTS 872-3100
(205) 453-3100

H. J. Christian, Mail Code ED43, FTS 872-2463
(205) 453-2463

O. H. Vaughan, Jr., Mail Code ED43, FTS 872-5218
(205) 453-5218

R. L. Frost, Mail Code EB23, FTS 872-2463
(205) 453-2463

P. H. Gillaspy (USRA), Mail Code ED43, FTS 872-5255
(205) 453-5255

S. J. Goodman (USRA), Mail Code EB43, FTS 872-1557
(205) 453-1557
McIDAS Lab FTS 872-2570

NASA ARC
Moffett Field, California

R. Erickson, FTS 448-6465
J. Arvesen, FTS 448-5376

NCAR/FOF
Boulder, Colordao

J. McCarthy, FTS 322-7651

NOAA/NSSL
Norman, Oklahoma

W. D. Rust, FTS 736-4926
D. R. MacGorman, FTS 736-4916
W. L. Taylor, FTS 736-4916

NOAA/Ness
Fort Collins, Colorado

J. W. Purdom, FTS 323-5285

NOAA/PROFS
Boulder, Colorado

R. Alberty, FTS 320-6849
R. Holle, FTS 320-6637

Kansas Air National Guard (U-2 Hangar)
Topeka, Kansas

FTS 913-862-1234
Ext. 4442

University of Wisconsin-Madison
Madison, Wisconsin

F. Mosher, FTS 262-3755
J. T. Young, FTS 262-6314

Bureau of Land Management
Denver, Colorado

D. Vance, FTS 303-234-4620

State University of New York
Albany, New York

B. Vonnegut, FTS 518-457-4607
R. Orville, FTS 518-457-3985

New Mexico Institute of Mining & Technology
Socorro, New Mexico

M. Brook, FTS 505-835-5611

APPROVAL

NASA THUNDERSTORM OVERFLIGHT PROGRAM – RESEARCH IN ATMOSPHERIC ELECTRICITY FROM AN INSTRUMENTATED U-2 AIRCRAFT PLATFORM

By Otha H. Vaughan, Jr.

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

William W. Vaughan

W. W. VAUGHAN
Chief, Atmospheric Science Division

G F McDonough

GEORGE F. McDONOUGH
Director, Systems Dynamics Laboratory

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